Operational Noise Manual

An Orientation
For
Department of Defense Facilities

November 2005

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Readiness thru Health

Operational Noise Manual

An Orientation
For
Department of Defense Facilities

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Forward

This manual was developed by the Operational Noise Program at the U.S. Army Center for Health Promotion and Preventive Medicine to be used by installation personnel as a tool designed to aid with the management of operation noise (formerly environmental noise). The Operational Noise Manual: Orientation for Department of Defense Facilities provides a practical reference for military and civilian personnel with duties and responsibilities in operational noise management.

Whatever your job, one of your responsibilities is to know, understand and implement current Department of Defense environmental policy and guidance. This manual provides you overviews of relevant noise regulations and policy. The majority of the manual is devoted to the following subjects: Characteristics of Sound; Effects of Noise; Military Noise Sources; Noise Monitoring; Reduction of Noise Conflicts and much more.

This manual is a product of a team approach to a need for a basic noise management reference. The principal authors are U.S. Army Center for Health Promotion and Preventive Medicine, Aberdeen Proving Ground, Maryland; U.S. Air Force Research Laboratories, Wright-Patterson Air Force Base, Ohio; U.S. Army Engineering Research and Development Center, Champaign, Illinois and Wyle Laboratories, Arlington, Virginia.

This is a dynamic document that will benefit from the experiences of its users. Please help with suggestions for continuous improvements by sending your comments to: Commander, U.S. Army Center for Health Promotion and Preventive Medicine, ATTN: MCHB-TS-EON, 5158 Blackhawk Road, Aberdeen Proving Ground, Maryland 21010-5403 or emailing them to: CHPPM-NoiseQuestions@amed.army.mil

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CHAPTER ONE

INTRODUCTION

The United States Department of Defense (DOD) has been a staunch advocate of noise planning for many years. In fact, many aspects of the noise program presently used for many civilian airports have their roots in DOD experiences. So, why should a military commander be concerned about noise? There are six principle reasons:

- Being a Good Neighbor
- Avoiding mission loss
- Avoiding Tort claims
- Complying with the National Environmental Policy Act (NEPA)
- Complying with the Federal Noise Control Act of 1972
- Adhering to DOD policy and directives

1.1 BEING A GOOD NEIGHBOR

The DOD has long recognized the importance of being a good neighbor. Being neighborly is significant because DOD employees often live in civilian communities that surround the installations. Long before noise impact analysis was required by law, the DOD was balancing the community's desire for noise reduction with its mission to equip and train our soldiers. Indeed, as early as 1957, the DOD began establishing procedures for estimating noise exposure and gauging community reaction to aircraft operations and by 1964, the DOD was working on the relationship between land use planning and aircraft noise. Even during those early days, the DOD recognized the need to address noise issues from a land use planning perspective and, as a result, rudimentary land use compatibility guidelines were established. For example, we now encourage city planners to zone such things as industrial parks in the noisy aircraft overflight areas and zone residential development in quieter areas.

1.2 AVOIDING MISSION LOSS

Military installations have a well-known tendency to attract activity from the civilian sector. In many instances, sizeable new communities have been built near an installation or existing communities have expanded toward or around an installation's boundaries. This growth process can place severe limitations upon the ability of a military installation to support training and maintain an adequate level of readiness for assigned units. As noise impacts upon these civilian communities increase from military activity, so does litigation and/or political pressures that could result in degradation of the installation's mission. More specifically, not only do the number of complaints to installation commanders increase dramatically, but also the number of complaints to members of Congress.

The consequences of this adverse public reaction to military operations can be the placement of limitations on the operations of some bases to the outright closure of others. One of the best examples of the degradation of mission performance due to urbanization occurred at the Naval Air Station (NAS) in Los Alamitos, California. When originally established during World War II, this NAS was in a rural area. But due to the poorly planned postwar residential expansion of southern California into Los Alamitos, the Navy could no longer routinely fly jet aircraft into the NAS. Consequently, the airfield now serves the needs of the California Army National Guard (ARNG) and the U.S. Army Reserve which, compared to the Navy, operates relatively few noisy flights.

A more recent example involving explosives was the Army Engineering School locates south of Washington D.C. With the expansion of suburbs into northern Virginia, the explosive weight of demolitions was lowered in order to avoid community noise complaints. Eventually, the school moved to Ft. Leonard Wood, Missouri.

Such classic encroachment problems can have an effect on military missions even if the installation is not closed down. Restrictions such as nighttime curfews, noise abatement procedures, bed down of weapons systems, and special court orders have all threatened mission readiness at many military installations.

In 2001, the Senior Readiness Oversight Council, chaired by the Under Secretary of Defense concluded that:

- “Encroachment on DOD ranges and training areas is a serious and growing challenge to the readiness of U.S. Armed Forces.”
- “Encroachment issues are many, are complex, and involve multiple federal, state and local agencies, as well as Congress and the public.”
- “Further, the impact of encroachment is broad–affecting our ability to execute realistic air, ground, and naval training across the nation, as well as beyond its borders.”
- “The Department of Defense needs a comprehensive and coordinated approach to addressing encroachment issues. The approach should include an outreach strategy to increase public awareness of how essential, realistic, and effective training is to the readiness of U.S. Armed Forces.”

1.3 AVOIDING FEDERAL TORT CLAIMS

Prior to 1970, noise impacts were addressed only in the legal system and citizens were able to receive compensation for noise impacts through the Federal Tort Claims Act.

Noise claims against the DOD have generally slotted into three main categories: 1) property damage, 2) "taking" of property use, and 3) personal injury. Examples of property damage include sonic boom damage to glass and plaster, loss of livestock from startle reaction, and a reduction in milk or egg production due to noise stress. Some examples of "taking" include such claims as loss of property, diminished enjoyment of the property due to noise, and a decrease in property values. Lastly, the personal injury claims usually result from an accident caused by startle reaction to a sudden onset of noise. Most claims were handled and paid for by the local installation and these myriad court cases has led to a haphazard method of dealing with noise issues.

1.4 COMPLYING WITH THE NATIONAL ENVIRONMENTAL POLICY ACT (NEPA)

The late 1960's and early 1970's were a watershed period for environmental issues because of the environmental movement was just beginning to coalesce. With this nascent movement came a new emphasis on incorporating environmental concerns into the planning process. The National Environmental Policy Act (NEPA) of 1970 directed federal agencies to explore all environmental impacts of any newly proposed action. DOD actions which may require NEPA review and EPA comments (under Section 309 of The Federal Clean Air Act) include: construction of new airfields or weapons ranges; new runway construction or extensions; proposed changes in flight corridors; modification of weapons ranges or deployment of new weapons systems; proposed increases in number of annual or night operations; and proposed changes in long-term airfield use, ground operations, and maintenance.

NEPA, Section 1500.2(f), instructs federal departments and agencies to "use all practicable means, consistent with the requirements of the Act and other essential considerations of national policy, to restore and enhance the quality of the human environment and avoid or minimize any possible adverse effects of their actions upon the quality of the human environment."

Noise itself was defined as a pollutant in the Clean Air Act. Section 309 (a), states "The Environmental Protection Agency (EPA) Administrator shall review and comment in writing on the environmental impact of any matter relating to duties and responsibilities granted pursuant to this Act or other provisions of the authority of the Administrator, contained in any ... newly authorized Federal projects for construction and any major Federal agency action ..." So, with the establishment of NEPA and the Clean Air Act, the EPA now has the responsibility to comment on anything affecting the quality of the environment.

1.5 COMPLYING WITH THE FEDERAL NOISE CONTROL ACT OF 1972

NEPA and the Clean Air Act required the DOD to assess noise but did not state exactly how. The Noise Control Act of 1972 addressed this issue and introduced order into the process of assessing noise impacts. This act mandated that the EPA publish a consistent standard of measurement for noise and a method of assessment that would be used for all federal agencies. As a result, the EPA Office of Noise Abatement and Control (ONAC), in conjunction with the National Academy of Sciences, set noise level goals for long-term health and welfare for communities. The EPA then promulgated standards for various noise sources. At about this time, the Federal Aviation Administration (FAA) also started to establish noise certification levels for civilian aircraft and these standards and certifications were directed to control noise mainly at the source (rather then at the receiver).

In the late 70s, several federal agencies, including the DOD, came together to establish the Federal Interagency Council on Urban Noise (FICUN) with the purpose of creating a consistent set of guidelines for determining the total noise impact on communities. Many of the current DOD land use compatibility guidelines were adopted as the method to determine noise impacts on these communities and FICUN published these guidelines in a 1980 report (FICUN 1980).

The EPA ONAC office was the major driver for consistent assessment procedures, interpretation, and policy among the federal agencies but in 1980, the EPA ONAC office lost its funding. The legal, administrative, and policy implications of that loss of ONAC funding are described in a report of the Administrative Conference of the United States (1988) and particularly critical for the DOD was the accompanying loss of interagency coordination for noise issues.

In response to citizen concerns in the late 1980s and the need for interagency coordination, the federal agencies again came together for two purposes. The first was to reassess the EPA's method of determining noise and the second reason was to establish the impact criteria from noise sources. To signify this broader mandate, the agencies changed their name to the Federal Interagency Committee on Noise (FICON) and in their report they reconfirmed the basic noise measurement standards as applicable for noise analysis (FICON 1992). At the same time, FICON also established a curve for assessing the impact of noise on sleep disturbance and established thresholds for judging significant impacts.

Forward to 1993 when FICON came together again, this time to concentrate on aviation noise. The Federal Interagency Committee on Aviation Noise (FICAN) was formed to provide forums for debate over the need for future aviation noise research and to encourage new development efforts in this area. All Federal agencies concerned with aviation noise are represented on the Committee including: the U.S. Army (USA), Air Force (USAF) and Navy (USN); the Departments of Interior (DOI) and Transportation (DOT); the Federal Aviation Administration (FAA); the U.S. Environmental Protection Agency (EPA); the National Aeronautics and Space Administration (NASA); the National Center For Disease Control (CDC); and the Department of Housing and Urban Development (HUD). Of these, the Air Force, Army, FAA, and NASA are currently sponsoring the majority of current research.

While FICAN does not conduct or directly fund any research (individual federal agencies control the direction and funding of their own research programs). It does serve as a forum for members to discuss research findings, identify topics requiring research, and solicit the public’s concerns about the effect of aviation noise. Additionally, the committee has a continuing goal of establishing consistent description, procedures, and policy on noise issues. Thus, it is expected that FICAN efforts will lead to expanded, coordinated, and cooperative research efforts among individual agencies that will result in more efficient use of federal funds.

Military and civilian noise planning efforts have benefited from mutual interest and efforts. One area in particular that has benefited is research and development where the greatest focus is on community reactions to aircraft noise, noise reduction technologies, noise effects on animals, and new or improved computer models. For instance, to better understand community reaction, the U.S. Army has conducted several investigations on annoyance. Moreover, the Air Force and NASA have each conducted research on sleep interference, and the Air Force has examined the feasibility of a prospective epidemiological study of the effects of aircraft noise exposure on human health.

Notable events in the genesis of this vast body of research include the Air Force and NASA research on sonic boom exposure in the 1960’s, the FAA’s on-going civilian aircraft certification, and the development of standard noise models and quieter jet engines. A practical application of this research can be found in the military’s KC-135R program where efficiency improvements and cost reductions came about through commercial efforts to reduce fuel costs and noise impacts of the Boeing 707. Other efforts have gone into developing engine test facilities, or “hush houses,” where engines can run at full power with dramatically reduced effects to the surrounding environment when compared with conventional testing procedures. In fact, noise abatement procedures are integrated into nearly all DOD flight schedules and aircraft operating procedures from simple modifications to flight tracks and imposition of quiet hours to the use of preferential runways.

Alternatively, Air Force research in advanced technology has been directed toward applications to engine test cells of active sound cancellation techniques, flight demonstration projects, and earplug design. Research conducted by the U.S. Air Force has also been instrumental in the study of the effects of aircraft noise on the environment, animals, and in the establishment of noise criteria for land uses. Within the subject of animals alone, the Air Force and the Army have researched noise effects on domestic, grazing, and wild animals, as well as on poultry and birds of prey. Of special interest to the military are the effects of overflights on Military Operating Areas (MOAs) and along Military Training Routes (MTRs).

Finally, recently a number of FICAN member agencies also started programs to develop new aircraft noise models and improve the existing models used for predicting both long-term and short-term exposure, as well as exposure from unconventional operations such as MTRs and sonic booms (FICAN Annual Reports). With these types of endeavors, the military's body of knowledge will continue to grow.

In summary, the differences between noise concerns for the military and the civilian sector continue to decrease. The exchange of technical noise information and assistance is imperative to address and solve the similar problems each interest faces. Requests from the civilian sector for joint use of military airfields are increasing as are large-scale joint service operations that include activities at civilian airports. Therefore, both civilian and military airfield operators must understand each other's mission requirements and their implications with regard to noise and land use planning.

1.6 ADHERING TO DOD NOISE POLICY AND DIRECTIVES

The DOD involvement in these interagency committees served to further increase the military's awareness of noise planning issues and to provide the basis for institutionalizing its programs. The DOD is very concerned about the impact of its training and missions on the environment and administers many active programs to manage the noise and mitigate the noise impacts from our operations. Furthermore, the DOD has formalized this concern in DOD directives and instructions. Within the three main military branches (Army, Air Force, and Navy), further service-specific instructions, handbooks, and guidelines have been created to enact this overriding DOD concern.

The following documents spell out DOD and service-specific noise policies:

- National Environmental Policy Act (NEPA), 1969.
- Executive Order 12088 – Federal Compliance with Pollution Control Standards.
- DOD Directive 5100.50 – “Environmental Security Directive”.
- DOD Instruction 4165.57, “Air Installations Compatible Use Zones,” November 8, 1977.
- DOD Instruction 4715.2, “DOD Regional Environmental Coordination,” May 3, 1996.
- DOD Instruction 4715.9, “Environmental Planning and Analysis,” May 3, 1996.
- DoD Directive 5000.1, “The Defense Acquisition System,” October 23, 2000.
- DOD Instruction 5000.2, “Operation of the Defense Acquisition System,” October 23, 2000.
- DOD Directive 3030.3, “Joint Land Use Study (JLUS) Program,” July 26 2004
- DoD Directive 3200.15, “Sustainment of Ranges and Operating Areas (OPAREAs),” January 10, 2003
- DOD Instruction 4715.13 - “DOD Noise Program,” November 15, 2005
- Air Force Air Installation Compatible Use Zone (AICUZ) Handbook.
- Air Force Instruction 32-7061 Environmental Impact and Analysis (EIAP) Handbook https://www.denix.osd.mil/denix/Public/Policy/AF/Instructions/toc.html
- Army Regulation 200-1, Chapter 7, 1997 http://www.usapa.army.mil/pdffiles/r200_1.pdf
- Army PAM 200-1, Chapter 7, 2002 http://www.usapa.army.mil/pdffiles/p200_1.pdf
- Navy Instruction 11010.36B Air Installation Compatible Use Zones (AICUZ) Program.
- USACHPPM Operational Noise Program Webpage. http://www.apgea.army.mil/dehe/morenoise/

This is not a complete list of all Service guidance, but the major programs for addressing noise issues within the DOD.

1.6.1 AIR INSTALLATION COMPATIBLE USE ZONE (AICUZ)

AICUZ is a DOD planning program which was developed in response to the growing incompatible urban development (encroachment) around military airfields. The AICUZ program policy is to promote land use compatibility through participation in local, regional, state, and federal land use planning control and coordination processes.

Historically, most DOD installations were built in the 1940’s and early 1950’s in relatively remote areas. Since then, urban growth has extended toward the boundaries of many of our installations and problems result when complaints over the effects of aircraft operations (e.g., noise, low overflight, etc.) lead to operational changes which negatively impact the flying mission. Incompatible encroachment has been a contributor to the cessation of flying missions and several base closures.

The AICUZ program has two objectives:

(1) Assist local, regional, state, and federal officials in protecting and promoting the public health, safety, and welfare by promoting compatible development within the AICUZ area of influence.

(2) Protecting DOD operational capability from those effects of land use that are incompatible with aircraft operations.

The AICUZ program is one of many land use determinants used by local planners and decision makers. The AICUZ handbook was developed by the Air Force and refined by the other services to provide specific instructions for defining operations around its air bases, calculating the noise exposure contours, giving recommended land use guidelines to the local community, and preparing a formal document for release to the public.

For the Army, airfield noise is generally less of a problem than the noise of weapons firing. At Army airfields, helicopters are the dominant aircraft and helicopters are not only quieter than jet aircraft, but also their pilots have far more flexibility in avoiding noise sensitive areas than they otherwise would in a fixed-wing plane.

The Navy and the Air Force operate both airbases and few large weapons training areas. The Navy expanded the AICUZ program used for its installations and has applied it to its military ranges. This formal program for weapons ranges is designated as the Range Compatible Use Zone (RACUZ). Similarly, to emphasize the inclusion of weapons noise along with aircraft noise, the Army in the 1980’s adopted the Installation Compatible Use Zone (ICUZ) program. The policy and procedures of ICUZ were essentially the same as for AICUZ. More recently, the ICUZ program has been incorporated into the more comprehensive Installation Operational Noise Management Plan (IONMP).

1.6.2 INSTALLATION OPERATIONAL NOISE MANAGEMENT PLAN (IONMP)

In incorporating the ICUZ into the Installation Operational Noise Management Plan (IONMP), the Army's purpose was to emphasize actions other than zoning as solutions to planning in the noise environment. While conducting ICUZ studies, Army planners discovered that many communities did not have zoning ordinances or other means to regulate new construction in land exposed to training noise.

With the IONMP, the primary strategies for protecting the mission of military installations from the problems of noise incompatibility are long-range land use planning and being a responsible neighbor to surrounding communities. The IONMP addresses these issues in a proactive, wide-ranging manner while the ICUZ element within the IONMP specifically assesses the compatibility of the noise environment with the land uses.

The other elements of the IONMP (including education of both the military and civilian communities, management of noise complaints, mitigation of the noise and vibration, the "Fly Neighborly" program, and noise abatement procedures) are aimed at being a responsible neighbor to the communities surrounding the installation.

Note: The Installation Operational Noise Management Plan (IONMP) was referred to as the Installation Environmental Noise Management Plan (IENMP) until 2004 when the name was changed in order to better describe the nature of the plan.

To accommodate the needs of the Army National Guard (ARNG) the Statewide Operational Noise Plan (SONMP) was developed. This plan includes all the ARNG training sites and aviation support facilities within the specific state.

1.6.3 NATIONAL ENVIRONMENTAL POLICY ACT (NEPA) ANALYSIS

The NEPA analysis consists of an evaluation of the environmental effects of a Proposed Action and its alternatives. Depending on whether or not it is found that an undertaking could significantly affect the environment, one of three levels of analysis and documentation is required: 1) A Categorical Exclusion (CATEX) determination, 2) preparation of an Environmental Assessment (EA), or 3) preparation of an Environmental Impact Statement (EIS). Air Force Instruction (AFI) 32-7061, the Environmental Impact Analysis Process (EIAP), and Army Regulation 200-2 (32 CFR Part 651, Environmental Analysis of Army Actions, Final Rule, 29 March 2002) describes the procedural requirements that must be followed by the Air Force and Army in order to comply with NEPA. Figure 1-1 presents a block diagram of the major steps in the Air Force's EIAP and these steps are comparable to those carried out by the Army and Navy.

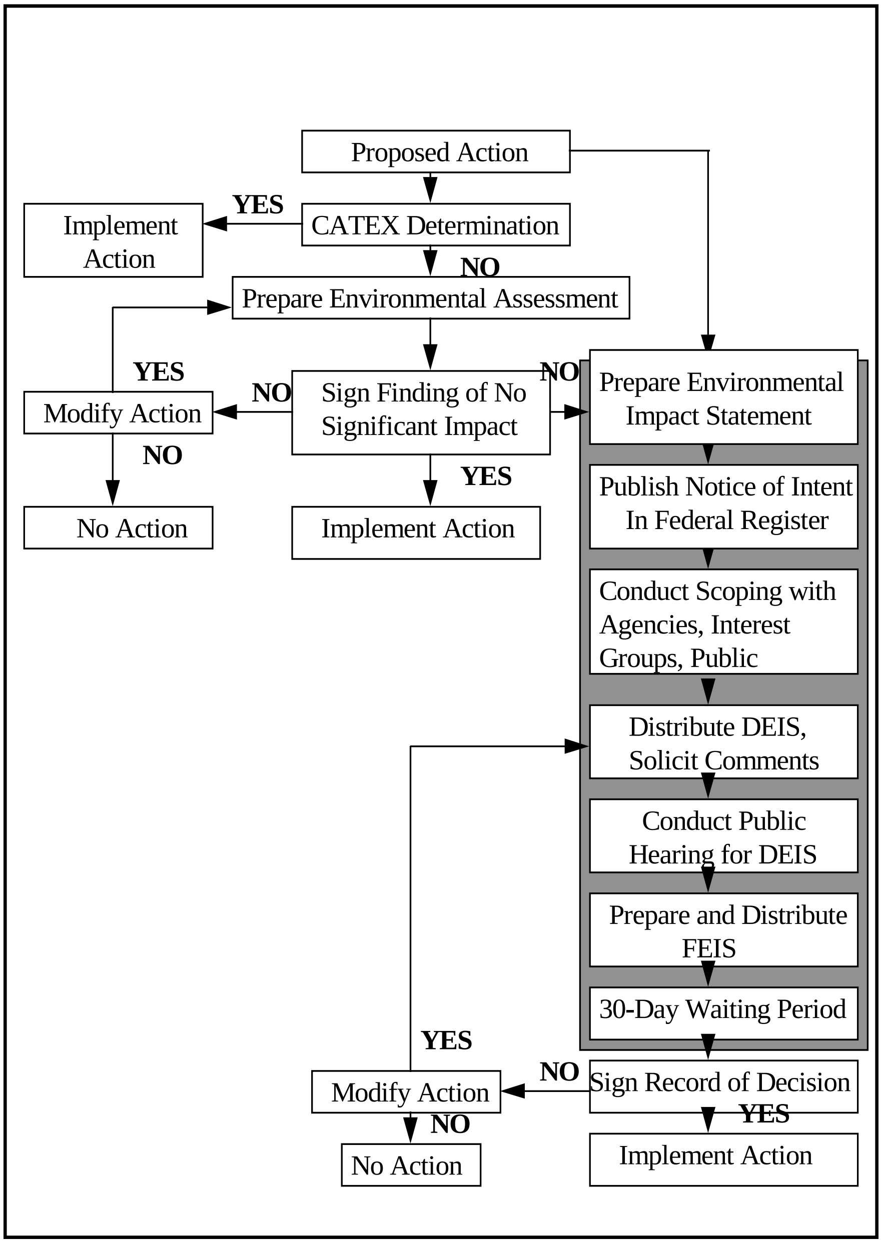

Figure 1-1 Environmental Impact Analysis Process (EIAP)

1.6.4 JOINT LAND USE STUDY (JLUS)

The Department of Defense Office of Economic Adjustment (under DOD Instruction 1983) sponsors the JLUS program. Its purpose is to help local communities fund comprehensive plan developments to resolve perceived community/installation land use incompatibilities. The JLUS program can provide technical and financial assistance to the planning agencies for developing master plans that are consistent (when economically feasible) with the noise, accident potential, and safety concerns of the local installation.

The scope of the JLUS program is divided into three major tasks:

- Conduct impact analysis to provide an in-depth review of existing and proposed land use patterns. This analysis projects the impact of current and future military missions on the surrounding jurisdictions.

- Create a land use and mission compatibility plan. This plan examines the impact analysis to identify conflicts in land use and provide alternative land use solutions. This plan also looks at the growth potential for adjacent areas and projects the impact on current and future compatibility.

- Develop a Land Use Compatibility Implementation Plan. This implementation plan lists a series of actions and proposals for adoption by local jurisdictions to resolve land use conflicts and move toward a compatible land use plan for the installation and the adjacent counties and communities.

  While these studies make certain recommendations, it should be kept in mind that each participating jurisdiction must decide which recommendations are best suited to their particular needs. The recommendations will be implemented at the discretion of the elected officials in each jurisdiction. The installation military commander's role is like that of any other major landowner. That is, as the leader of the military community, the commander has a great influence and will make recommendations for zoning, but he or she must be careful to not overstep their legal authority. The final zoning decisions reside with the local officials.

1.7 PURPOSE AND ORGANIZATION

In summary, the DOD's desire to be a good neighbor in the surrounding communities, wish to avoid potential impacts on mission readiness, need to minimize tort claims, eagerness to comply with congressional actions (such as the National Environmental policy Act or NEPA), and various internal directives and policies require DOD personnel to be aware of noise impacts and to mitigate them whenever possible. To address these concerns about noise, the user must first understand noise, how it is measured, the sources of noise and its impacts, the tools available to assess its impact, and the options for mitigation.

This manual is a tutorial on noise environments for military installation planners and those assessing its impact. It is to be used as a tool for understanding noise and what can be done to mitigate its impact. This manual is **not** the procedure for developing environmental management documentation (i.e., NEPA documentation, IONMP, AICUZ, etc.). While Chapter 1 has provided an overview of the procedures and analysis, specific information is available in the technical memoranda issued by DOD agencies.

Chapter 2 contains information about the characteristics of noise including noise states, the fundamentals of noise, and noise measures. It also explains such terms as decibel, frequency, and propagation.

Chapter 3 covers noise effects from simple annoyance to its impact on health.

Chapter 4 covers military noise sources including fixed and rotary wing aircraft, armored weapons, guns, small arms ranges, mortars, rockets, and explosives. This chapter is provided as an aid to understanding the noise in order to mitigate its impact.

Chapter 5 discusses noise modeling which is used to predict the noise levels from the various sources identified in this manual. The DOD has developed many computerized models to predict the various noise measures and these models may be used to assess the impact even before the noise is generated.

Chapter 6 focuses on noise monitoring. Noise monitoring is often required to document the noise, settle disputes about noise exposures, and verify the predictions of the noise models. There are several methods of sampling discussed in this chapter.

Finally, Chapter 7 examines what can be done to reduce noise conflict. The discussion here centers on the three areas to consider when mitigating the noise impacts: noise source modification, blocking the noise along the path or exploiting some aspect of noise propagation, and noise receiver modification.

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CHAPTER TWO

CHARACTERISTICS OF SOUND

2.1 FUNDAMENTALS OF SOUND

Sound is a physical phenomenon consisting of minute vibrations that travel through a medium such as air or water. Audible sounds are those vibrations sensed by the human ear. Our human experience of sound depends on both the pattern of vibrations from the source as well as the way our hearing mechanism interprets these vibrations.

As an object vibrates back and forth in the atmosphere, it collides with the surrounding air particles creating a pressure disturbance. These air particles collide with adjacent air particles, thus causing the pressure disturbance to spread away from the source of vibration. At the ear this disturbance generates a vibration in the eardrum that is transmitted via a network of bones in the ear to the cochlea. The cochlea then converts the vibration into an electrical signal interpreted by the brain as sound.

The alternate bunching ("***compression***") and spreading ("***rarefaction***") of the air particles results in a variation of pressure above and below the base atmospheric pressure (as shown in Figure 2-1). This "sound wave" travels in air at about 1,100 feet (335 meters) per second but in other mediums, the speed of sound will vary depending upon the temperature and density of the medium (see Table 2-1). The distance between successive compressions or successive rarefactions is the ***wavelength*** of the sound and the number of compressions or rarefactions (per unit time) is the ***frequency*** of the sound.

Sounds can bring us important information and pleasure, but depending on content, people can be annoyed by sounds that bring neither. The pleasantness or unpleasantness of a sound is largely dependent on the receivers and their predisposition to the sounds. The content of a sound is determined by three defining characteristics: 1) its spectral or frequency content, 2) its level or intensity, and 3) its time pattern.

2.1.1 FREQUENCY CHARACTERISTICS OF SOUND

2.1.1.1 RANGE OF HUMAN HEARING

Sound frequency is measured in terms of cycles-per-second (cps), or hertz (Hz), which is the preferred scientific unit for cycles-per-second. The normal human ear can detect sounds ranging in frequency from about 20 Hz to about 20,000 Hz. All sounds in this wide range of frequencies, however, are not heard equally well by the human ear which is most sensitive to frequencies in the 1000 to 4000 Hz range.

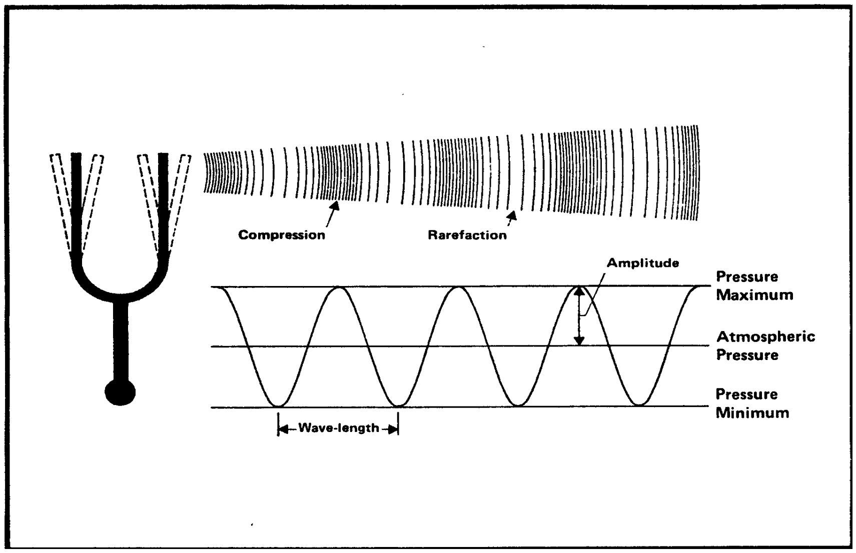

Figure 2-1 Acoustics of a Pure Tone

Transmission Medium	Meters per Second	Miles per Hour
Air*	331	741
Oxygen*	316	707
Helium*	965	2158
Hydrogen*	1284	2871
Water (0^0 C)	1402	3135
Water (20^0 C)	1482	3314
Water (50^0 C)	1543	3450
*at 0^0 C		

Table 2-1 Sound Speeds in Various Media

As discussed previously, a vibrating object produces a sound wave with a characteristic frequency. An isolated pure tone, such as illustrated in Figure 2-1, does not exist in the natural soundscape. In nature, a particular sound is a complex combination of frequency components produced by the many different vibration and oscillatory modes of the sound source. Consequently, each frequency component may be of different magnitude and may vary as a function of time.

So, in order to properly represent the characteristics of a sound source, it is necessary to divide the total signal into its frequency components or *spectrum*. Knowledge of the frequency spectrum of a signal is important because:

- People and animals have different hearing sensitivity and react differently to various frequencies. For instance, everyone is familiar with a “dog whistle” that dogs can hear but humans cannot. This is because the dog whistle produces a tone that is at a frequency above human hearing but within the range of the dog’s hearing. At the other end of the frequency scale, it was recently discovered that elephants communicate at frequencies below the range of human hearing.

- Structures respond to much lower frequencies than humans (e.g., 1 to 30 Hz). Therefore, infrasound that people cannot hear can still create problems by inducing vibration into buildings.

- Different sources have different frequency characteristics.

- Engineering solutions for reducing or controlling sound are frequency dependent.

2.1.1.2 THE SPECTRUM OF SOUND

To measure the spectrum, acousticians use a mathematical procedure known as Fourier analysis to break down the complex pattern of sound into a set of sine waves. Fourier analysis shows how much energy is at each frequency in the complex waveform. Figure 2-2 shows the results of a Fourier analysis of the pure tone depicted in Figure 2-1. Notice that all of the energy is located at a single frequency.

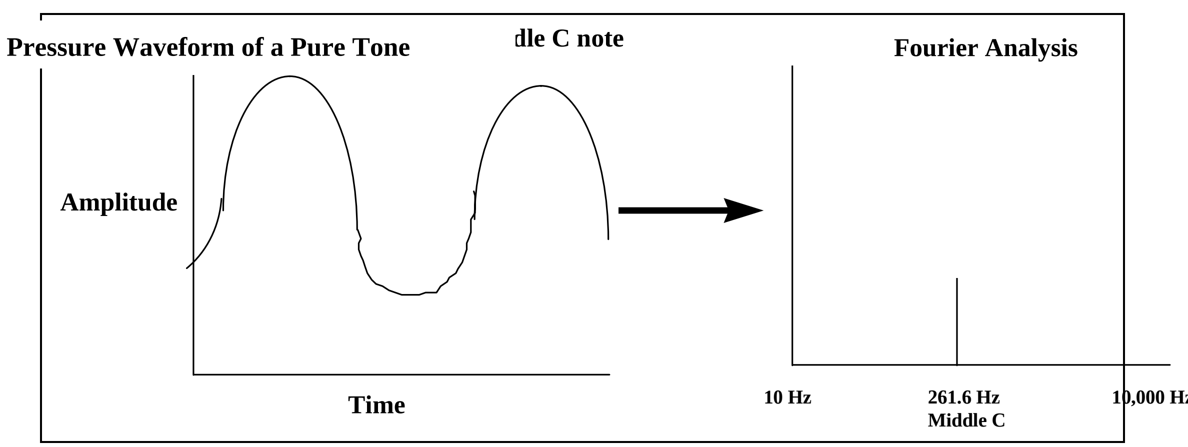

Figure 2-2 Fourier analysis of a Pure Tone

Now, the primary frequency in the spectrum of a piano’s middle C is 261.6 Hz and for a pure tone at 261.6 Hz, the spectrum would be a single vertical line as seen in Figure 2-2. But Figure 2-3 shows the actual spectrum for middle C piano note. It consists of a number of harmonics (multiples of the primary frequency) with the largest one at 261.6 Hz. These are extracted from the overall signal (C_1) and shown as the various multiples (C_4, C6, and C_8). Furthermore, Figure 2-4 shows the spectrum of a typical jet exhaust noise. Notice these spectra show most of the energy being in the range of 250 to 500 Hz just like the piano middle C. The difference is that piano spectrum is composed of regular harmonic intervals which give a much more pleasant sensation than the random frequencies of the jet noise.

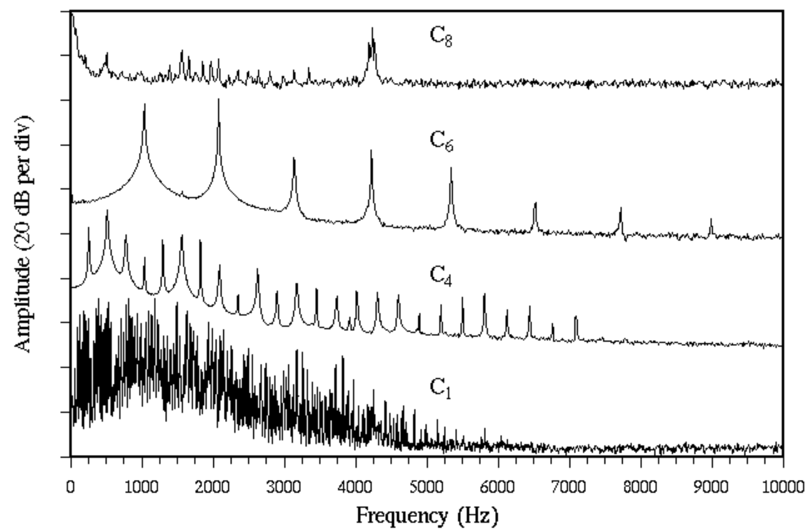

Figure 2-3 Fourier analysis of Piano C Notes

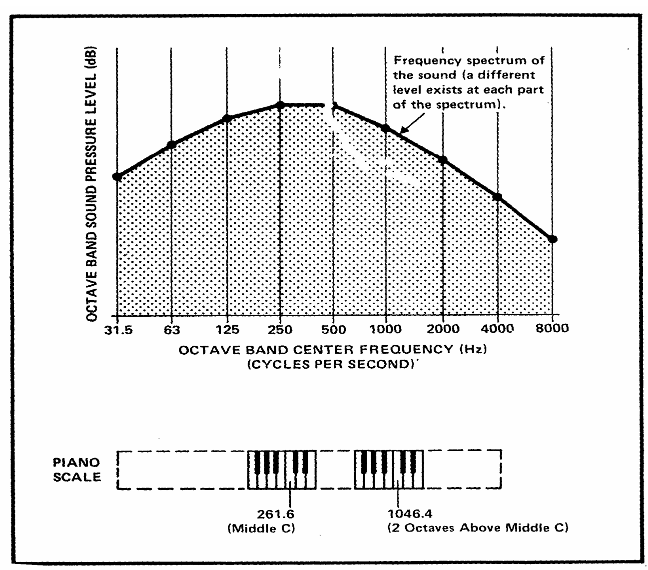

Figure 2-4 Typical Spectrum of Jet Exhaust Noise

2.1.2 LOUDNESS AND DECIBELS

The decibel (dB) is a useful tool in describing the loudness of a sound. Historically and for obvious reasons, the first scientists who seriously studied the ear's response to sound pressure were telephone engineers. These engineers soon found that the ear responds to a broad range of pressures and, for a healthy human ear, a 1,000 Hz tone can be detected at a pressure of 20 micropascals or 20μPa (which is equal to 20 x 10^{-6} Pascals or .0002 microbars). Figure 2-5 shows the ratio of this pressure to detection pressure across the range of human hearing.

With the ear responding to such a large range of pressures, the early telephone engineers had a measurement problem. At threshold (where the ear could detect a pressure of .0002 microbar) an increase of .0004 microbars was a significant change, yet at 10 microbars, an increase of .0004 microbars was completely undetectable. Thus, the telephone engineers needed a more convenient way to measure sound and their solution was a logarithmic scale based on a ratio to a set level.

To elaborate, a logarithm (base 10) is simply a power of 10. Thus, 10 x 10 is the same as 10^2, which of course equals 100. The logarithm of 100 is then 2 (log 100 = 2). Similarly, 10^3 is 10 x 10 x 10 = 1,000 therefore, the log of 1000 is 3. The logarithm-based scale gives us the relative strength of a signal in a range that is detectable by a human and closely matches the human perception of sound. Recall that the pressure that is barely detectable by the human ear (the threshold) is 20μPa (2 x 10^{-6} Pascals or .0002 microbars). By using this as a reference, the telephone engineers “zeroed” the logarithmic scale. This unit of measure (a logarithmic ratio with a reference at the threshold of hearing) was branded the “bel” in honor of Alexander Graham Bell. Over time the bel proved to be too coarse of a unit so it was divided by 10 to produce the “decibels” we now use (abbreviated as “dB”).

Therefore, the pressure in dB equals ten times the log of the measured pressure divided by 20μPa. Figure 2-5 shows the relationship between sound pressure and decibels.

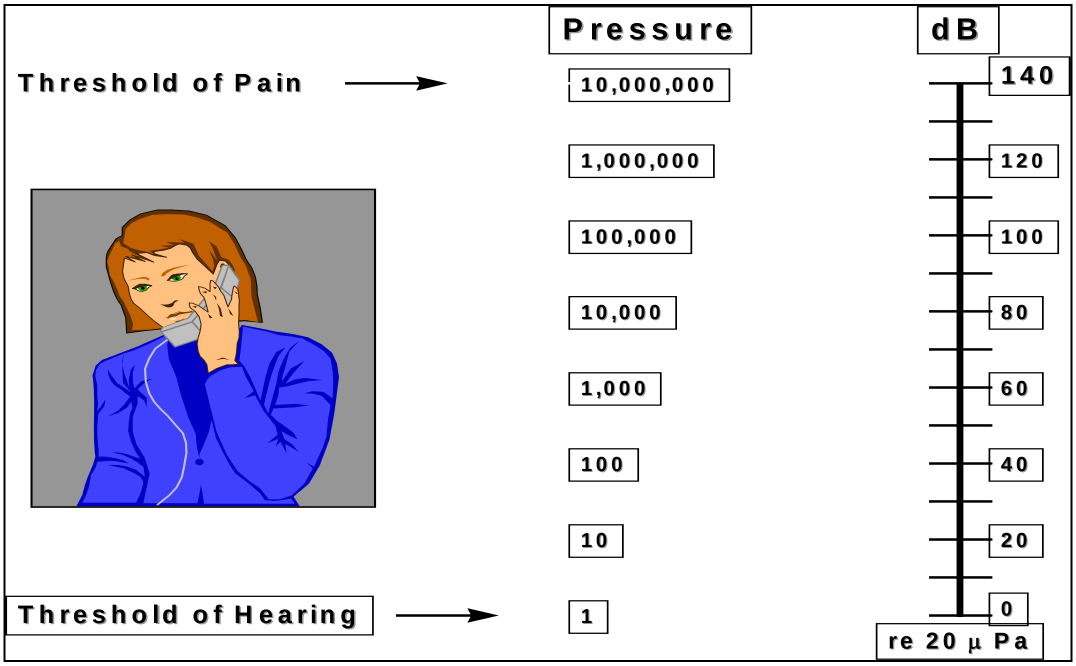

Figure 2-5 Relation between Sound Pressure and Decibels

2.1.2.1 UPPER TOLERABLE LIMIT OF LOUDNESS

The decibel can be used to define the tolerable limit of loudness. The level of sound is usually measured from the threshold of human perception which, as discussed above, is about 0 dB for a 1000 Hz tone with a reference of 20 μPa. The upper limit of tolerance, though, depends on the level, frequency, and duration of the sound. For example, a 20 msec rifle shot at 140 dB can damage hearing in some unprotected ears but a howitzer shot at 140 dB (which is not as "sharp" as a rifle shot) is less likely to cause damage. Alternately, a passing sound at 120 dB will cause only discomfort but several minutes of exposure to 120 dB can cause damage. Moving further down the scale, as much as 8 hours of exposure to A-weighted 85 dB (weighting scale will be discussed later) will cause little or no hearing loss.

Since people do not generally live in places so loud that their hearing will be damaged, environmental noise studies are primarily concerned with sound at amplitudes below the threshold of hearing loss where, speech interference, rattles, and common annoyance are the main considerations.

2.1.1.2 SENSITIVITY TO CHANGES IN LOUDNESS

When two half-second tones are presented to trained subjects with a half second of silence between the two tones, humans are able to detect a difference of 0.5 dB. However, when comparing sounds in our everyday experience, we are less sensitive to differences in sound intensities. From a practical standpoint, a three-decibel difference (which is a doubling of the sound **energy**) is generally noticeable to the average listener. A change in sound level of about 10 dB is usually perceived by the average person as a doubling (or halving) of the sound's **loudness**. This relation holds true for loud sounds and for quieter sounds across the speech frequencies but not at the lower frequencies of human hearing.

So, in short, because of the nonlinear response of the human ear (as with most human senses), a decrease in sound level of 10 dB actually represents a 90 percent decrease in sound intensity but only a 50 percent decrease in perceived loudness.

2.1.1.3 ADDING DECIBELS

Because of the logarithmic nature of the decibel, dBs do not add directly. And since the dB is a translation of the real sound intensity, when two sounds are present at the same time the sound intensity will double but the dB value will only increase by 3 (see formula below).

Pressure (dB) = 10 log (Measured Pressure/20 Micropascals)

Table 2-2 illustrates a “short cut” approach to decibel addition. So, to add 90 and 90, the table indicates that 3 dB must be added to give 93 dB. And to add 90 and 95, 1 dB is added to 95 to yield 96 dB. Figure 2-6 illustrates how to add more than two sound levels together. The levels should be rank ordered, and then added together two at a time starting with the lowest two levels.

When two Decibel Values Differ By:	Add the Following To the Higher Value
0 to 1 dB	3
2 to 3 dB	2
4 to 9 dB	1
10 or more dB	0

Table 2-2 Shortcuts to Decibel Addition

NOTE: To add more than two levels, start with the lowest value. This method is only an approximation of how to add sounds together. To get an exact answer, the pressures must be added together and then converted to the decibel form.

PROBLEM:

Determine the sum of the followng noise levels.

SOLUTION:

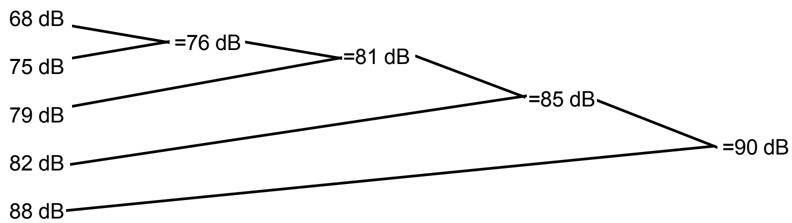

Figure 2-6 Estimation Method for Adding Sound Sources

2.1.1.4 EQUAL LOUDNESS CONTOURS

The perception of loudness is not consistent across frequencies. For instance, at any sound pressure less than 90 dB, a 1000 Hz tone would sound louder then a 100 Hz tone. This is a result of the natural human hearing response to sound levels. If we map these equal loudness phenomena (levels perceived as equally loud to a human observer), we notice change as a function of both frequency and intensity.

Figure 2-7 is a graph of “equally loud” or *equal loudness* contours based on the work of Fletcher and Munson of Bell Labs in the 1930’s. Notice that the contours for a 1,000 Hz are evenly spaced and the contours for low frequencies are spaced closer near threshold. This illustrates that the loudness of a low frequency tone increases faster at threshold than at high levels. Also, it takes a much higher intensity of low frequency sound or higher frequency sound (relative to 1000 Hz) to be perceived by the human ear. Put another way, a low frequency sound is not perceived as loud because we simply do not hear it. These curves of equal loudness level are described in “phons” and, essentially, a number like 50 phones means that the sound is as loud as a 50 decibel, 1000Hz tone.

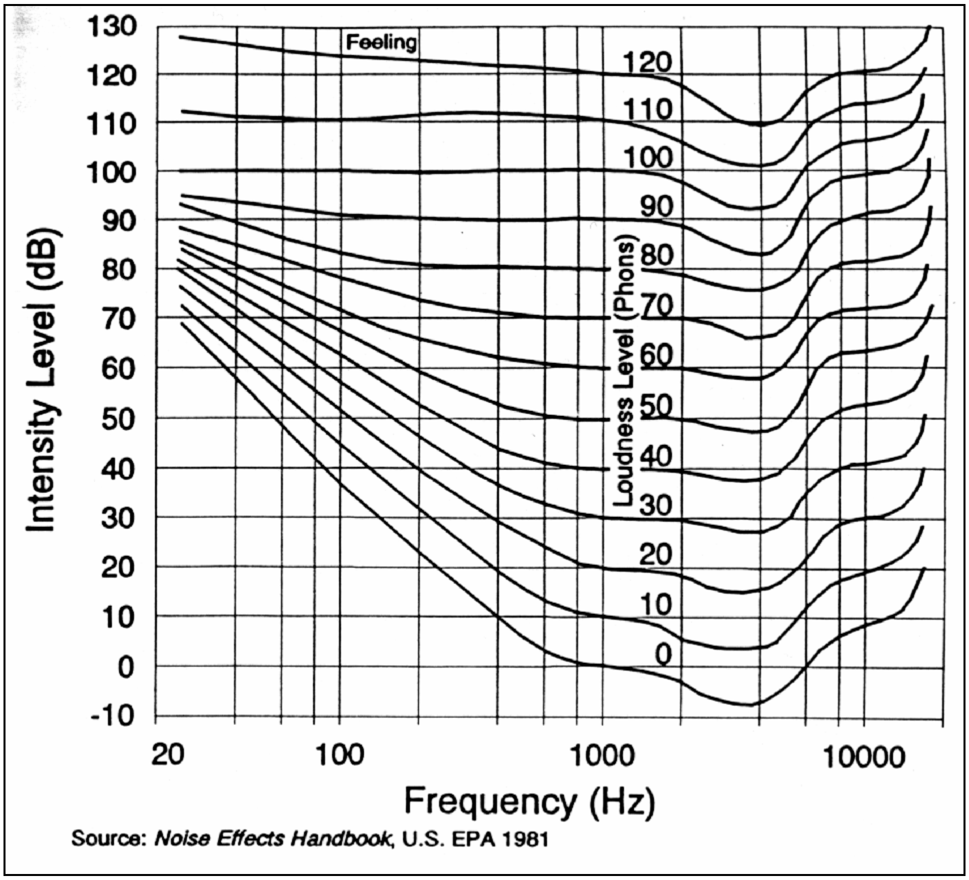

Figure 2-7 Equal Loudness (Fletcher-Munson) Contours

The loudness curves are important for understanding the annoyance of military explosions such as demolitions, sonic booms, tank guns, and artillery. As will be explained further in Chapter 4, most of the sound energy from these sources is below 30 Hz. For a 30 Hz sound to be as loud as a 1000 Hz sound at 80 dB, the 30 Hz sound must only increase 30 dB above threshold. We experience this as a rapid growth in loudness and this rapid growth in loudness is one of the reasons that a small increase in the level of an explosion can lead to a large increase in annoyance.

2.1.2.5 CALCULATION OF LOUDNESS

Weighting Scales

As stated previously, psycho-acousticians developed the equal loudness contours in the 1930s. Once they were published, acoustical engineers worked to develop instruments that would measure equal loudness and the result was three weighting scales: A, B, and C.

The A-scale was designed to approximate the lowest curve, the C-scale to approximate the highest curve, with the B-scale for in between. To use this set of scales, the person measuring the sound first had to define the overall level and then switch to the proper weighting. The idea was a good one but there were two problems. First, it was hard for people to keep switching around from one scale to another as the intensity of sound changed. Second, the B and C scales did not prove to be very accurate in predicting the loudness of a broadband sound. Eventually, people stopped using the B scale altogether and the B scale isn't even an option on contemporary sound level meters (see Figure 2-8).

In 1973, the National Academy of Sciences recommended that the A-weighted scale be the primary descriptor of sound for human use and it is abbreviated as "dBA." The A-weighting is a frequency dependent adjustment of sound level used to approximate the naturally range and sensitivity of the human auditory system.   The C-weighting, on the other hand, is still used for intense signals containing low frequency sound energy (near or below the threshold of human hearing) like large gun blasts and sonic booms that tend to educe annoyance through building rattles.

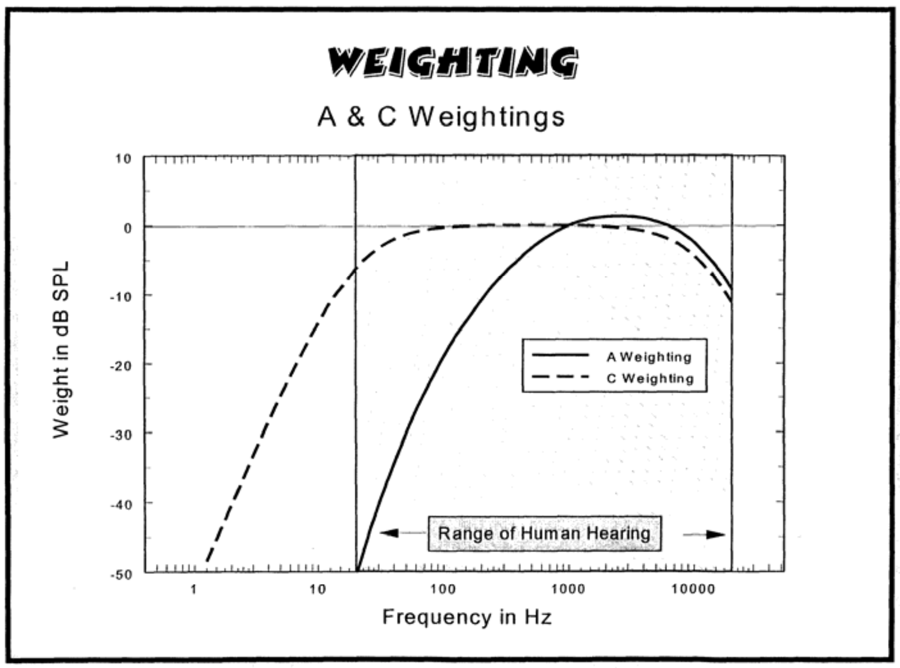

Figure 2-8 A and C Weighting Scales

<u>Loudness in Sones</u>

The failure of the B and C scales as measures of loudness was due to the physiology of the auditory system. As with any network of neurons, auditory neurons interact with each other through excitatory and inhibitory connections. At the Harvard Acoustics Laboratory, psycho-acoustician S.S. Stevens developed another method for approximating the way the auditory system summed up the acoustic energy at different frequencies. To calculate loudness using Stevens' method, the acoustician looks at the frequency component and levels, adding them up using the phon curves, to arrive at a single number. This single number equates to how loud a person perceives this complex sound and is labeled in "sones." By definition, 1 sone equals a 1000 Hz tone 40 dB above threshold (or 40 phones) and the sones basically double with every increase of 10 phones (2 sones ≈ 50 phones, 4 sones ≈ 60 phones, 8 sones ≈ 70 phones, etc.)

Perceived Noise Level

In the 1950s, Dr. Stevens' method for calculating loudness inspired another pioneer, Dr. Karl Kryter, to adapt the method to predict the annoyance of aircraft overflights. Using the same concept, Kryter developed a set of contours for noise not based on equal loudness but based on equal annoyance. These equal annoyance curves, or "Noy Curves," have a unit of "noy" and are then summed into a perceived noise level (PNL) which is measured in the unit PNdB. The relationship between the two is akin to that between sones and phones:

$$\text{PNdB} = 40 + 10 \log_2 (\text{noy})$$

The PNL gives a slightly better descriptor of how annoying a sound would be and was developed because the high frequency component of jet aircraft was found to be more annoying than one would find by using a simple A-weighting.

2.1.2.6 MEASUREMENT OF LOUDNESS

Most sound level meters used to measure the intensity of sounds are set up to allow measurements in the A, C, or unweighted (linear) scales. In addition, specialized sound level meters are available for the direct measurement of loudness. Sound level meters are programmed to calculate loudness using a procedure published by the International Standards Organization (ISO) and the procedure is based on the work of Dr. Stevens in the U.S. and Dr. Eberhard Zwicker in Germany. For some sound sources, the measurement of loudness using the ISO standard can offer advantages over A-weighting. Currently, the DOD and other Federal agencies are continuing to use A-weighting as the primary measure of loudness and no change in policy is anticipated at this time.

2.1.3 CHARACTERISTICS OF SOUND AS A FUNCTION OF TIME

The third aspect used to describe sound (after frequency and loudness) is its relative stability over time. The temporal pattern of sound is important in predicting annoyance. Sound can be classified into three basic categories that define its basic time pattern: steady state, transient and impulse. A fourth term, ambient, is commonly used to represent the normal background sound levels one would experience in a local area.

2.1.3.1 STEADY-STATE SOUND

Steady state sound is a sound of consistent level and spectral content. Typical examples of steady state sound are the sounds produced by ventilation or mechanical systems that operate more or less continuously. Another example pertinent to our discussion would be aircraft ground run-up sound. People's annoyance to steady state sound depends on the level of the sound and the time exposed. Generally, the longer the sound goes on, the higher the annoyance people will experience. As a general rule, one can expect the same annoyance at a lower sound level for a steady state sound than for a transient sound and people are particularly annoyed by a steady state sound containing hums or tones. When tones are present in a sound, some noise laws and standards will actually add a penalty (typically 5 dB) in assessing the noise level. This means that a steady state noise with a discernable tone would be as annoying as 5dB higher noise source without a tone. This also means that if you can remove a tone from the noise source you will usually have a noticeable decrease in the annoyance experienced from that source.

2.1.3.2 TRANSIENT SOUND

Transient sound is sound that can be clearly defined as an event having a beginning and an end where the sound temporarily rises above the background and then fades back into it. In reality, all sound is temporary for if you remove the source, the sound goes away. But, transient sounds are typically associated with "*moving*" sound sources such as an aircraft overflight or a single vehicle drive-by. Transient sound is typically less than several minutes in duration and the annoyance of a transient sound is dependent on both the maximum level and the duration. To capture these two factors, Federal agencies use a measure known as the Sound Exposure Level or **SEL**. The SEL provides a convenient single number that adds the total acoustic energy in a transient event and it has proven to be a good number to judge the relative annoyance of different transient sounds.

2.1.3.3 IMPULSIVE SOUND

Impulsive sound is of short duration (typically less than one second) and high intensity. It has abrupt onset, rapid decay, and often a rapidly changing spectral composition. Impulse sound is characteristically associated with such sources as explosions, impacts, the discharge of firearms, the passage of supersonic aircraft (sonic booms), and many industrial processes.

2.1.3.4 AMBIENT SOUND

The term "ambient" connotes the ever-present collection of sounds of both natural and man-made origin. Natural ambient noise, or “natural sound,” is defined as any non-mechanized sound. In some instances, individual natural sounds (cicadas, frogs, etc.) can exceed natural ambient sound levels. Man-made sounds, such as that produced by rail and street traffic, are considered part of the ambient sound environment in normal urban settings.

The major reason for interest in the effect of ambient sound is the possibility that the level of aircraft sound around airports relative to the existing ambient sound can produce either a masking (one sound covered by another sound) or an enhancement effect on the audibility of the aircraft and, thus, on human annoyance in response to the aircraft sound. Of particular concern to the DOD is the natural soundscape in areas administered by the National Park Service and the U.S. Forest Service. Figure 2-9 shows the ambient “natural sound” measured in different areas of the Grand Canyon National Park reproduced from a 1995 National Park Service Report on the effects of aircraft overflights on the National Park System. In areas with extremely low ambient noise levels, sounds can be detected at distances much greater than area with higher ambient noise levels. For example a typical small aircraft can be detected (heard) above the ambient noise in a typical urban setting at about 1 mile away but the same aircraft flying in the same conditions could be easily heard in Superstition Canyon at a location 10 or even 20 miles away. This is because the detectability of the sound is always dependant on the signal to noise ratio. In this case the signal (aircraft noise) stays at the same level but the masking effect of the ambient noise (remote canyon vs. typical urban) ambient noise is vastly different.

2.2 CUMULATIVE PERCEPTION OF MULTIPLE SOUNDS

Up to this point, we have looked at various ways to describe the physical and perceptual characteristics of a single sound such as that from a passing airplane or a single gunshot. However, community judgments about the suitability of a sound environment are rarely based on a single sound. Instead, we experience multiple sources of sound that cumulatively add to our overall perception of a “quiet” or “noisy” neighborhood. In 1974, the Environmental Protection Agency (EPA) put forth a procedure to assess the cumulative, 24-hour exposure for citizens of the United States. This procedure was published in what has become known as “the Levels Document.” To understand this procedure, one must understand three key technical terms: Sound Exposure Level (SEL), Equivalent Level (L_{eq}), and Day-Night Average Sound Level (DNL).

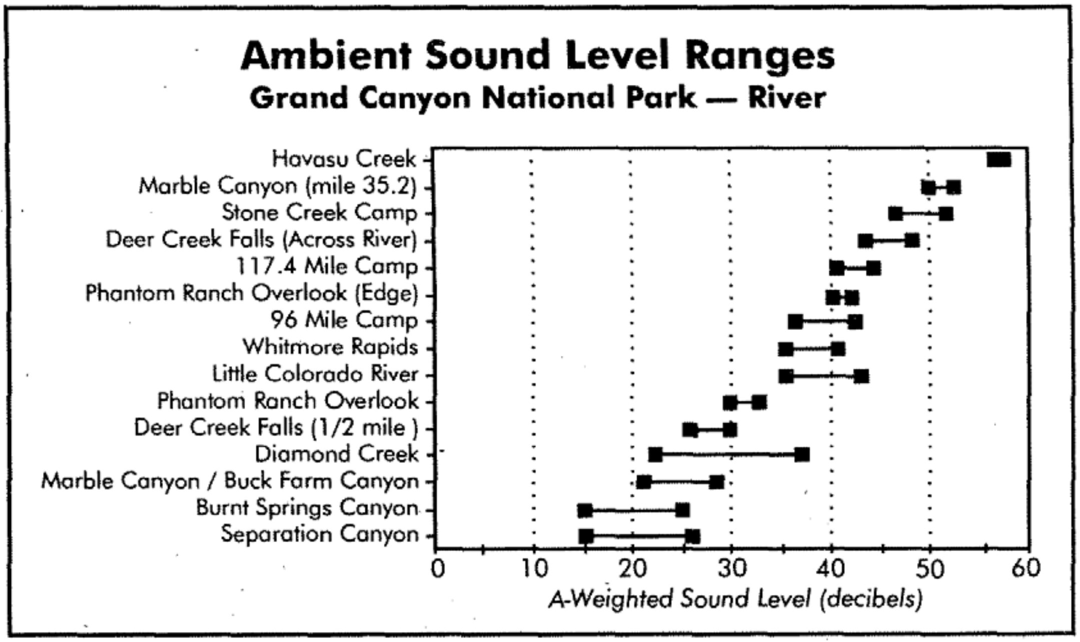

Figure 2-9 Measured Ambient Sound Levels Along the Colorado River in Grand Canyon National Park.

2.2.1 CUMULATIVE PERCEPTION AND LONG-TERM ANNOYANCE

Although sounds are experienced individually (whether they are simple or complex sounds) there is a cumulative effect on humans. A drip of water is not very annoying but the cumulative effect of continued dripping will begin to rise up in one's consciousness and ultimately trigger annoyance. In a similar manner, a single event like an aircraft overflight might not pose a problem but continual exposure and its cumulative effects could cause much annoyance across a wide group of people. While not much is known about how long it takes for a person to become annoyed by a sound, some research has suggested that humans have an annoyance "rise time." Although it is not exactly known how long it takes (and probably varies from person to person), research has shown that an individual's level of annoyance from a series of irritating aircraft flyovers will increase over several weeks to several months and finally arrive at a stable "long term" annoyance (Fidell *et al.*, 1985). This "long term" annoyance has been shown to be fairly stable in numerous studies in various cultural settings and planning in the noise environment is usually based on this "long term" annoyance.

2.2.2 CUMULATIVE NOISE MEASURES

Subjective tests indicate that human response to sound is not only a function of the maximum level, but of the duration of the signal and its temporal variation. Time-related changes might range from a sound level constant over time, as produced by a continuously operating machine, to the constantly varying sound levels perceived near highways and (even more so) around airports.

Over the past 30 years, a wide variety of acoustic measures or rating scales have been developed for the purpose of quantifying the sound generated by particular sources. These measures of sound have been described by the Acoustical Society of American (ASA) and defined in their American National Standards Institute (ANSI) publication, *Acoustical Terminology (ref ANSI S1.1, 1994).*

This multiplicity of measures has resulted from wide variations in the description of spectral and temporal characteristics among sound sources. For an engineering analysis of the noise exposure of a particular source, one measure may have many advantages over another. For management of noise at DOD airfields and military training routes, only four cumulative measures are important: Sound Exposure Level (SEL), Equivalent Level (L_{eq}), Day-Night Average Sound Level (DNL), and the Onset Rate Correction.

2.2.2.1 SOUND EXPOSURE LEVEL (SEL)

The annoyance of an intrusion increases with both the level and the duration of the intrusion. Thus a long duration low intensity event can be as annoying as a high intensity shorter event. The Sound Exposure Level (SEL) is a way of capturing the annoyance of both variables in terms of a single number. The SEL (as illustrated in Figure 2-10) is defined as the total acoustic energy in an event from background to background (typically computed from 10 to 20 dB from the event peak) normalized to one second. This single number represents all the acoustic energy of an event as if it occurred within a one second period.

2.2.2.2 EQUIVALENT LEVEL

Annoyance increases with the number of times an intrusive sound is experienced during a given period of time. The equivalent level (L_{eq}) is a way of capturing the annoyance of the number of intrusions by taking the average acoustic energy over a period of time. The period can be any length, but it usually is taken as some meaningful block of time such as an 8-hour L_{eq} for the office or a one-hour L_{eq} for a classroom lecture. The L_{eq} is defined as the level of continuous sound over a given period that would deliver the same amount of energy as the actual time-varying sound exposure. Figure 2-11 illustrates how the daily variation of traffic noise can be summarized in terms of a single value of a 24-hour L_{eq}.

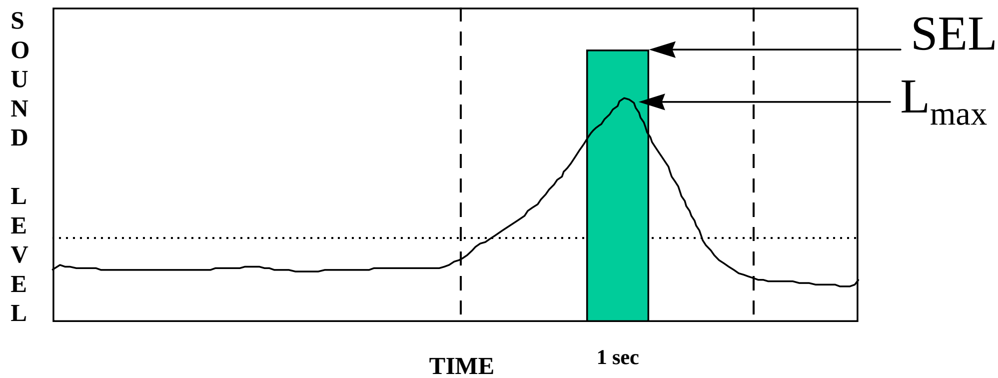

Figure 2-10 Sound Exposure Measure of a Transient Noise Source

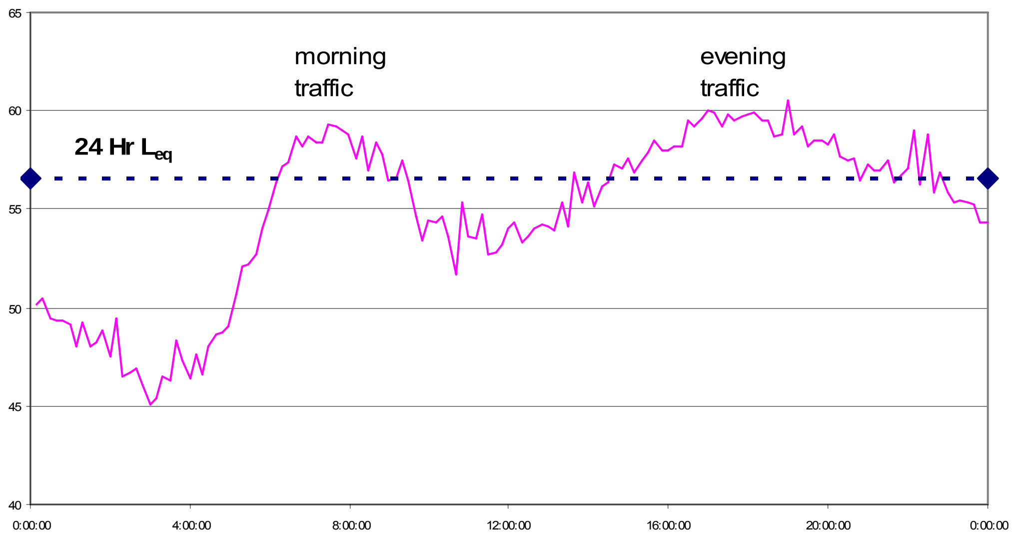

Figure 2-11 Equivalent Noise Level (L_{eq})

2.2.2.3 ADDING THE NIGHTTIME PENALTY FOR A 24-HOUR MEASURE

Annoyance is greatest when an intrusive sound occurs during the night. To capture the heightened annoyance of nighttime noise, the EPA recommended a special kind of 24-hour L_{eq} known as the DNL (or sometimes referred to as L_{dn}).

The DNL is calculated in two parts: a fifteen-hour daytime L_{eq} (0700 to 2200) and a nine-hour nighttime L_{eq} (2200 to 0700). The difference is, when calculating the 24-hour DNL, the nighttime L_{eq} is treated as if it were 10 decibels higher to account for the additional irritation of noise at night

It should be noted that, in recommending the 10 dB nighttime penalty, the EPA did not intend their measure to be used to predict sleep disturbance but only to capture the added annoyance of nighttime operations. Different procedures are needed to estimate sleep disturbance and these will be discussed in Chapter 3.

Note: In California a slight variation on this measure was adopted for all noise analysis. The California procedure adds an evening penalty of 5dB (from 1900 to 2200) in addition to the 10dB nighttime penalty. This measure is called the Community Noise Equivalent Level (CNEL).

2.2.2.4 ADDING THE ONSET RATE PENALTY

In recommending the DNL for general use, the EPA also recommended that environmental planners use the 365 day, annual average DNL. For people living along flight routes, the annual average DNL underestimated their annoyance. For this reason, USAF developed a special version for assessing noise in flight routes called the L_{DNmr} that adds penalties for the sudden increase in noise (onset) and sporadic nature of the sounds.

The “m” in L_{DNmr} is used to define the intermittent nature of aircraft operations along routes and in ranges (usually averaged over a monthly period) and it accounts for the normal time it takes for people to build up long-term annoyance. The “r” accounts for the added annoyance from the “surprise factor” of the high onset rates.

In effect, the L_{DNmr} metric is the same as the L_{dn} when operating conditions are similar to those around air bases. But flights along routes and in ranges may exhibit substantial variation throughout the year. These sporadic conditions require the dedicated L_{DNmr} scale because particular training phases or exercises that last for periods of weeks or months are, in some cases, underestimated in the annual averages.

2.3 OTHER NOISE MEASURES FOR ASSESSING AIRCRAFT NOISE

Before the EPA introduced the DNL, the DOD and other Federal agencies were using other single event and cumulative measures. Within the United States, assessments made with these earlier cumulative measures are primarily of historical and legal interest. Nevertheless, these measures are still important when assessing the noise of military operations in other countries (e.g., Japan) and one should always be aware of which measuring scheme is being used in which country.

2.3.1 PERCEIVED NOISE LEVEL (PNL)

Perceived Noise Level (PNL) is the rating of the “noisiness” of a sound, calculated from acoustic measurements and measured in perceived noise decibels (PNdB). The PNL is calculated from sound pressure levels measured in octave (or 1/3-octave) frequency bands and the frequency adjustment is based on the “Noy” Curves discussed earlier. This rating is most accurate in scaling the annoyance of broadband sounds of similar time duration that do not contain strong discrete frequency components.

2.3.2 TONE-CORRECTED PERCEIVED NOISE LEVEL (PNLT)

The tone-corrected perceived noise level (PNLT) is, logically, the PNL with an adjustment for pure tones. This adjustment is described in an American National Standards Institute (ANSI) and an International Standards Organization (ISO) standard. This measure attempts to account for human sensitivity to strong discrete frequency components in the noise signal over and above the sensitivity to high frequency noise. It is used to measure the effect of different noise durations on the annoyance such as in the case of aircraft flyovers at different velocities or distances.

2.3.3 EFFECTIVE PERCEIVED NOISE LEVEL (EPNL)

Effective Perceived Noise Level (EPNL) is a single number rating of the noisiness of complex aircraft flyover noise signals. It is calculated by the integration with time of tone-corrected perceived noise levels (PNLT) during a single noise event (such as an aircraft flyover). The EPNL includes adjustments for the relative duration of the noise signal and presence of audible pure tones or discrete frequencies (such as the whine of a jet engine compressor or fan). The reference signal is 10 seconds.

2.3.4 COMPOSITE NOISE RATING

Composite Noise Rating (CNR) was one of the first methods for integrating the PNL into a single number characterizing the annoyance of a 24-hour exposure. Even though today, the CNR is only of historic interest, it set an important precedent through a correction for ambient background and a 10-decibel nighttime penalty. Another precedent set with CNR was the use of noise contour maps showing areas where noise levels would be incompatible with residential use.

2.3.5 NOISE EXPOSURE FORECAST

The Noise Exposure Forecast (NEF) incorporated the tone and duration improvements to the PNL and, as with the CNR; the NEF enjoyed a brief period of use within the U.S. In 1974, it was replaced with a new procedure endorsed by the U.S. Environmental Protection Agency (EPA) but the NEF remains the primary noise descriptor used to describe airport noise exposure in Canada.

2.3.6 RELATIONSHIP BETWEEN NOISE MEASURES

All of the noise measurements are built either on either an equal loudness (A-level or Equal Loudness curves) or equal annoyance (PNL or Noy Curves) foundation. This parallel relationship between the various measures used by the DOD, other Federal agencies, and other countries is shown in Figure 2-12.

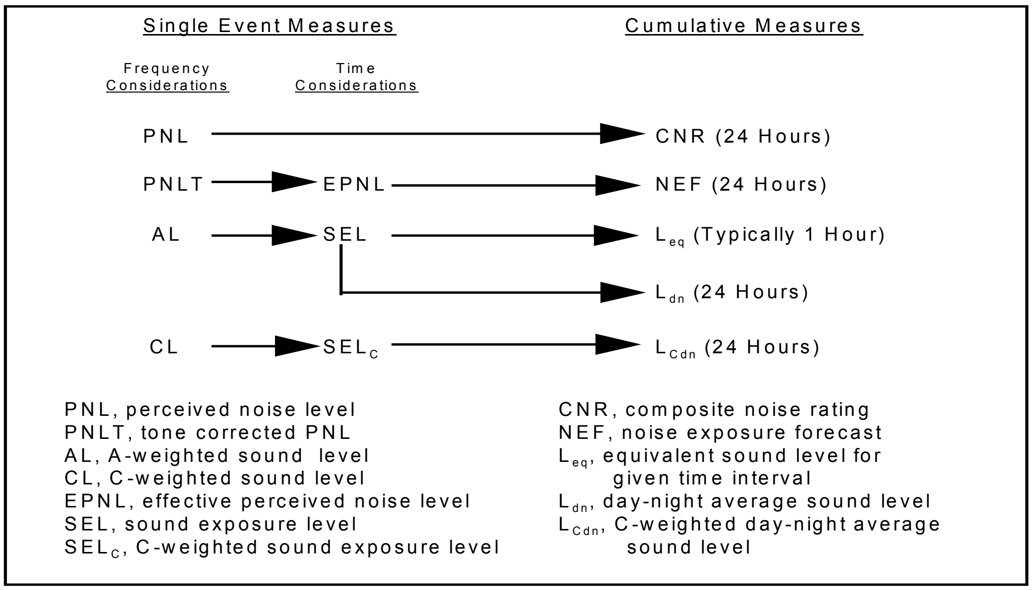

Figure 2-12 Relationship between Noise Measures

2.4 NOISE MEASURES FOR ASSESSSING WEAPONS NOISE

2.4.1 SMALL ARMS

Small arms are assessed using PK15 (met) or the A-weighted SEL for single shots. Corrections are added to the SEL to reflect the greater annoyance associated with impulsive sounds.

2.4.2 SONIC BOOMS AND LARGE WEAPONS

When explosions or sonic booms are intense enough to rattle windows, the appropriate measure for single shots is either the PK15 (met) or the C-weighted SEL. Cumulative exposures are assessed using the C-weighted DNL.

2.5 SUMMARY

This chapter explored the various methods for describing the physical parameters of sound. It began with ways to describe a single sound (such as a gun shot or a passing airplane) and concluded with ways to describe the cumulative exposure to sounds over periods of 24 hours or longer. Chapter 3 will relate the physical parameters of sound to various adverse effects on people, animals, and property.

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CHAPTER THREE

THE EFFECTS OF NOISE

Whereas Chapter 2 focused on the physics of sound, Chapter 3 will focus on the negative effects of sound which have been bundled under the general term “noise impacts.” Some of the impacts from noise include communication interference, hearing damage, startle reactions in people and animals, interference with tasks, and vibration in buildings.

Noise is usually defined as unwanted sound–sound that disturbs our routine activities, peace and quiet, and/or causes a feeling of annoyance. Whether the sound is interpreted as pleasant (like music) or unpleasant (like a barking dog) depends largely on the listener's current activity, past experience, and attitude toward the source of that sound. It is often true that one person's music is another person's noise so different reactions to the same sound are to be expected.

Although the primary concern is the effects of noise on people, preparation of NEPA documentation may also require analysis of noise effects on animals, structures, and property values. All of these are discussed in this chapter.

3.1 IMPACT ON PEOPLE

The effects of noise on people include annoyance, interference with communication, task interference, hearing loss, sleep disturbance, impact on learning, health effects, and aesthetic considerations. To a large degree the most prevalent issue with noise is annoyance so the DOD policy on assessing environmental noise is anchored in scientific studies of annoyance. However, to fully assess the impact of any proposed action (as prescribed by law) many factors must be considered.

3.1.1 ANNOYANCE

There is little doubt that annoyance is a subjective experience. We may be annoyed at our children, spouse or the neighbor and, if asked, we can even say the degree of our irritation (slightly, very, extremely, etc.). We can also communicate how long we have been annoyed, whether it has been for years or just today. Knowing the degree of noise annoyance experienced by an individual or a community of individuals is important to understanding the effects of noise on people. Presumably, if people are not annoyed by the sounds they are hearing, the sound is not harmful to their health or quality of life.

In the research of annoyance and the public's reaction to sounds, annoyance is generally measured using social surveys on which interviewees are asked to report their degree of annoyance with various noise sources. Early surveys were conducted mainly by door-to-door interviews but the advent of the telephone and computer has allowed researchers to widen participation at a lower cost of time and capital.

It is worth noting that researchers are usually interested in the long-term annoyance experienced by the community as a whole so when conducting interviews, extreme care is taken to obtain a representative sample of the community.

3.1.1.1 THE DOD'S USE OF "HIGH ANNOYANCE"

Social surveys of this type have been taken in many countries and with different noise sources. Unfortunately, comparisons between surveys are difficult because the questions have been asked in different ways and different languages. But in 1978, Schultz overcame this problem through a measure he called "percentage of high annoyance." He limited his analysis to surveys in which there was a scale running from "not annoyed" to "extremely annoyed" then he defined "high annoyance" as the top two categories on a 5-point scale (with adjustments for scales with fewer or more categories). The resulting "Schultz curve" offered two advantages:

First, it provided a mathematical equation for reporting the impact of a specific noise exposure measured in a single metric (DNL). Therefore, when preparing NEPA documents (which require a comparison between alternatives), this equation allows for easy quantification of the resulting impact (annoyance).

Second, it provides the DOD with a way to evaluate the relative annoyance of sonic booms, small arms fire, and heavy gunfire in comparison with civilian transportation noise. This is important because, if a DOD installation has to make noise, the maximum annoyance that the installation's neighbors experience from various military sources should be no greater than the maximum annoyance recognized as "reasonable" for the neighbors of commercial airports, busy highways, and railroads. The Schultz curve allows this determination to be made.

3.1.1.2 VARIABILITY OF ANNOYANCE JUDGMENTS

Figure 3-1 shows the data from which Dr. Schultz calculated his curve. Each data point in Figure 3-1 shows the average "high annoyance" reported by a group of interviewees exposed to a particular DNL along with the boundaries for 90% of the data points. These boundaries are more than 10 dB apart, which (in acoustical terms) is quite a difference showing that people from different communities may judge the same noise level very differently.

The Schultz curve predicts the typical response to a DNL exposure from roads, trains, or commercial airplanes. And modifying and modulating this typical response are a number of non-acoustic variables (discussed in greater detail in Chapter 7). Some of these variables are personal (e.g., an individual's noise sensitivity) and other variables may be shared by people across the community. In fact, the Green and Fidell research team has published a "family" of Schultz curves representing variability in a community's "subjective yardstick" for judging "high annoyance" (Green and Fidell, 1991). By assuming citizens in communities share a high, medium, or low threshold for reporting "high annoyance," they have been able to reduce the variability within individual data points thus making the resulting curve even more representative of actual levels of annoyance.

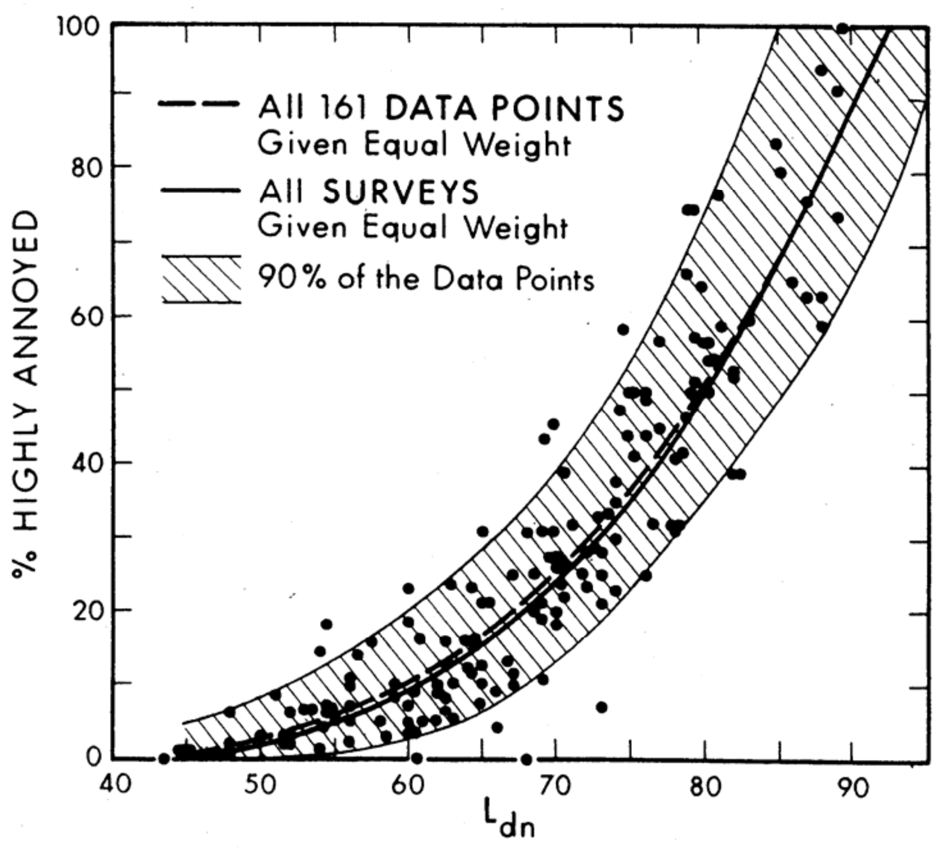
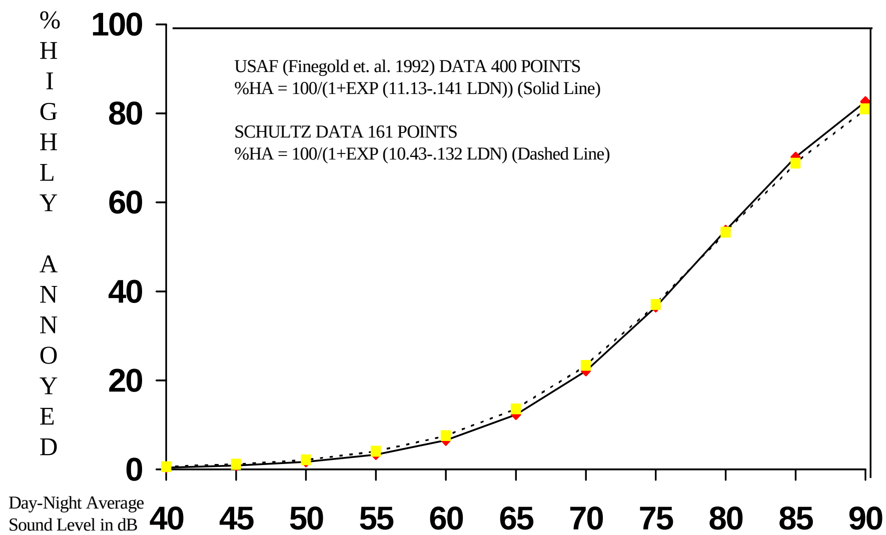


Figure 3-1 1978 Schultz Curve (with original data)

3.1.1.3 RELIABILITY OF THE SCHULTZ CURVE

The Schultz curve has stood the test of time. Studies completed worldwide have consistently shown this curve to be a good predictor of typical community annoyance. In 1991, the Air Force funded an update to the curve that included additional social survey data performed since 1978 (Fidell, 1991) and the resulting curve, shown in Figure 3-2, was almost identical to the original work. Now, both the DOD and the FAA are using this updated relationship to predict the prevalence of annoyance due to aircraft noise in communities.



Calculated %HA Points											
USAF	0.41	0.831	1.66	3.31	6.48	12.29	22.1	36.47	53.74	70.16	82.64
SCHULTZ	0.576	1.11	2.12	4.03	7.52	13.59	23.32	37.05	53.25	68.78	81

Figure 3-2 Comparison of Schultz Curve and USAF Analysis

3.1.1.4 VARIABILITY OF ANNOYANCE JUDGMENTS FOR EXPLOSIONS, SONIC BOOMS, AND GUN FIRE

As stated earlier, the Schultz curve shows the typical percentage of “highly annoyed” people to be expected at a given DNL. The variability shown in Figure 3-1 is from populations exposed to transportation noise and the DNL from transportation noise is about the same from one day to the next. But for explosions, sonic booms, and gunfire, the variability in annoyance judgments is much greater because of the inconsistency of the offending sounds.

Job (1988) found that typically less than 20% of the variation in individual reaction is accounted for by noise exposure and this was found to be particularly true for community response to gunfire. For example, in 1979 Army researchers conducted a large social survey around Fort Bragg, North Carolina (Schomer, 1982).   The results (Table 3-1) show the range of judgments from people living next to the south boundary and southwest boundary of Fort Bragg in the vicinity of howitzer firing points.   One can see that, in the same area where 18.1% of the residents were extremely annoyed, 19.4% said that they never heard blast noise. Similar variability was found in a social survey of communities around Fort Lewis, Washington (Schomer, 1985) and a ten-decibel disparity was found between the annoyance curves from two U.S. communities exposed to sonic booms (Fields, 1997).

How Annoyed are You by Blast Noise at Your Home?	
Extremely annoyed	18.1%
Very much annoyed	12.5%
Moderately annoyed	23.6%
Slightly annoyed	11.1%
Not at all annoyed	15.3%
I never hear blast noise	19.4%

Table 3-1 Example of the Range of Annoyance Judgments from Citizens Living in the Highest Blast Noise Exposure Zones at Fort Bragg, North Carolina (1979)

3.1.1.5 STANDARDIZING THE QUESTIONS ON AN ANNOYANCE SURVEY

Although the use of "high annoyance" allowed the plotting of data points from many different studies on the same graph, there are still many published studies in which the phrasing of questions precludes this type of analysis. To avoid this problem in future research, there has been an effort to standardize annoyance questions across countries by equating across languages (Fields, 1996a). Fields recommends the use of a verbal and a numeric question on each survey such as those in the following examples:

<u>Example of Verbal Question</u>**:**

"Thinking about the last 12 months or so, when you are at home, how much would you say the noise from (...noise source...) bothers or annoys you; Very much, moderately, a little or not at all?"

<u>Example of Numeric Question</u>**:**

"Next we have a ten-point opinion scale for giving your feelings about (...source...) noise when you are at home. If you are not at all annoyed, choose zero; if you are extremely annoyed, choose 10; if you are some where in between, choose a number between 0 and 10. Thinking about the last 12 months or so, what number from 0 to 10 best shows how much you are or annoyed by (…source…) noise?"

3.1.1.6 USE OF ADJUSTMENTS TO EQUATE NOISE EXPOSURES IN TERMS OF HIGH ANNOYANCE

A key element of the DOD environmental noise policy is setting acceptability limits for different kinds military noise so that the limits for each will result in the same percentage high annoyance. To implement this policy, adjustments are added to noise from low altitude military training routes (MTR), small arms fire, and sonic booms/heavy weapons.

3.1.1.6.1 ADJUSTMENTS FOR MILITARY TRAINING ROUTES

Unlike that of airports or airbases, Military Training Route (MTR) noise environments are typified by infrequent military aircraft overflights that are often at low altitudes and high speeds. To compensate for the “startle factor” associated with these operations due to the high onset of the noise, a penalty was imposed on overflights with high onset values. The *onset* is the rate at which the noise level increases as a function of time and this penalty, which can increase the SEL (used to calculate DNL) value by as much as 5 dB, is based on that rate.

This penalty function was derived from laboratory and field data (Bennett *et al*., 1992; Stusnick *et al*., 1992; and Stusnick *et al*., 1993) and to compensate for the infrequent activity on an MTR, the study examined in the busiest month of activity. The units adjusted by the onset penalty and infrequent activity are described by the symbol L_{DNmr} where the “$_m$“ denotes using highest monthly activity and the “$_r$“ denotes adjustment for the rapid onset rate. All predictions of subsonic aircraft noise on MTRs use the L_{DNmr} metric. Please see Chapter 2 for a more detailed explanation of the $L_{DNmr.}$

3.1.1.6.2 ADJUSTMENT FOR SMALL ARMS NOISE

The annoyance of small arms can be adequately assessed using the A-weighting of the sound level meter. However, the impulsive character of small arms noise adds to the annoyance as compared to a more continuous noise, such as traffic noise. Thus, to account for the added annoyance, a 12 dB penalty is added to the SEL of small arms noise. This penalty is not assessed for "rapid firing" which is typically defined as an aggregate firing rate greater than 30 shots per second. The penalty is based on multiple scientific and social surveys conducted around military and civilian firing ranges, primarily in Europe (Vos, 1995; Buchta, 1990).

In adding a 12 dB penalty to the noise of small arms, care must be taken that the sounds are actually audible at the receiver’s location. Such as, a small arms range collocated with a highway, the noise from the highway may mask the impulsive sound, and adding a 12 dB penalty to the impulsive noise would be misleading. It has been found that small arms fire is usually not a concern unless the linear peak sound pressure level of individual shots is above 85 dB (Sorensen and Magnusson, 1979; Hede and Bullen, 1982). Also, small arms fire is generally less of a problem at the larger DOD installations because there is enough land for a buffer between ranges and the community that the off-post level rarely reaches 85 dB.

While the 12 dB adjustment is the simplest approach to dealing with the added annoyance of small arms noise, annoyance may be modified by other variables for which adjustments are not added. The following are several examples of the complications that may be encountered when trying to measure the annoyance of small arms fire:

- People living near small arms ranges do not always hear the shots as distinctly separate events. In addition to the merging of single shots during bursts of firing, several soldiers may fire at the same time. As a result, people living near a military rifle range hear short periods of intense firing followed by longer periods of silence as soldiers check their targets and take care of jammed rifles. Under these conditions, the number of shots becomes less important than the decibel level of the typical (average) shot. For instance, in a survey of 400 randomly selected people living around 2 military and 3 civilian firing ranges in Germany, the decibel level of the average shot was twice as important in predicting annoyance as the annual number of rounds fired (Buchta *et al*., 1982).

- Near some military ranges, people found the machine gun bursts to be more annoying than rifle fire. Furthermore, near civilian ranges, they found the double gunshot from clay pigeon shooting to be the most annoying (Buchta, 1990) of all small arms fire. The increased annoyance from two (or more) closely spaced shots results from the loudness of the second shot being added to the loudness of the first shot (Ogura *et al.,* 1993).

- Experiments from Holland suggest as much as a 4-decibel bonus for ranges that restrict the number of shooting days by concentrating weapons training on fewer days (Vos, 1992). This says that people living near ranges would rather have the firing concentrated into a shorter period of time than having it spread out through the week or month (Buchta, 1990).

- Swiss environmental noise regulations are written to give a 3-decibel bonus for halving the number of afternoons and mornings of firing (Hofman *et al*., 1985).[1]

3.1.1.6.3 ADJUSTING DNL FOR LARGE IMPULSIVE SOUNDS

Large impulsive sounds are unique to the military except for industrial explosions such as mine quarry blasts. Because of their low frequencies (below the threshold of human hearing), the impacts of sounds like sonic booms and heavy weapons blasts are mainly noticed inside buildings when things rattle or sound resonates in rooms. Using the A-weighted scale to measure these large impulsive sounds underestimates their true annoyance so, acousticians have used two adjustments:

- The first adjustment is to measure with C-weighting instead of A-weighting. Since buildings respond to low frequency noise, a C-weighted metric is required to adequately assess these impacts. A sound level meter set to C-weighting will usually give a larger number than a meter set to A-weighting (refer back to Figure 2-8).

- In addition, there is an equation for adjusting the annoyance of large impulsive sound measured with C-weighted DNL to the equivalent annoyance of aircraft measured with A-weighted DNL. Such equations have been derived through various social surveys of human response to sonic booms and large caliber gun firings.

The Army has been studying the annoyance of large gun noise since 1971 and the Air Force was studying the annoyance of sonic booms even earlier. What has been learned is that the factors most important in predicting whether citizens will be annoyed by gunfire or booms are:

- How loud is the gun or boom?
- How often do people hear the gun or boom?
- Does the noise rattle the house?
- What time of day does the gun or boom occur?

<u>Loudness</u>

As discussed in Chapter 2, the sound of a large gun or explosion has most of the acoustic energy at low frequencies. Once low frequency sound is audible, the increase in loudness for each decibel increase is more rapid than for sounds in the speech frequencies. To understand this

[1] The Swiss regulations account for the half -day of use. A half-day is a morning or an afternoon. On Sundays, however, a half-day counts as 3 half days to account for the fact that people are most annoyed on Sundays. The Swiss regulations give about three times more weight to the number of half days than to the number of shots per year.

phenomenon, the reader may want to refer back to Figure 2-7 which shows that the "loudness steps" for low frequencies are smaller than the "*loudness steps*" for mid-frequencies. Because of these differences, a one decibel increase for a low frequency "boom" may equate to a two decibel increase for an aircraft flyover (Fidell *et al*., 1998).

<u>Incidence of Hearing the Event</u>

Thirty years ago, British researchers demonstrated that the number of explosions and loudness are interrelated when predicting annoyance (Webb and Warren, 1967). Participants in the experiment were living in a small village and Monday and Tuesday of each week, the researchers set off 24 explosions. On the Wednesday, they asked the villagers how they felt about the explosions. Figure 3-3 shows what happened over the course of 14 weeks. In the first week, about half of the villagers were annoyed but by the ninth week, about a quarter were annoyed. Then, in the tenth week, the researchers tripled the explosions to 72 and annoyance jumped higher than it was in the first week. Annoyance came back down with a return to 24 explosions, but it jumped up again in the 14th week when the pressure of the blasts was doubled. These findings are consistent with the equal energy hypothesis (i.e., L_{eq}). The increased annoyance after tripling the number (a 5 dB increase in L_{eq}) was about the same as after a doubling of pressure (a 6 dB increase in L_{eq}).

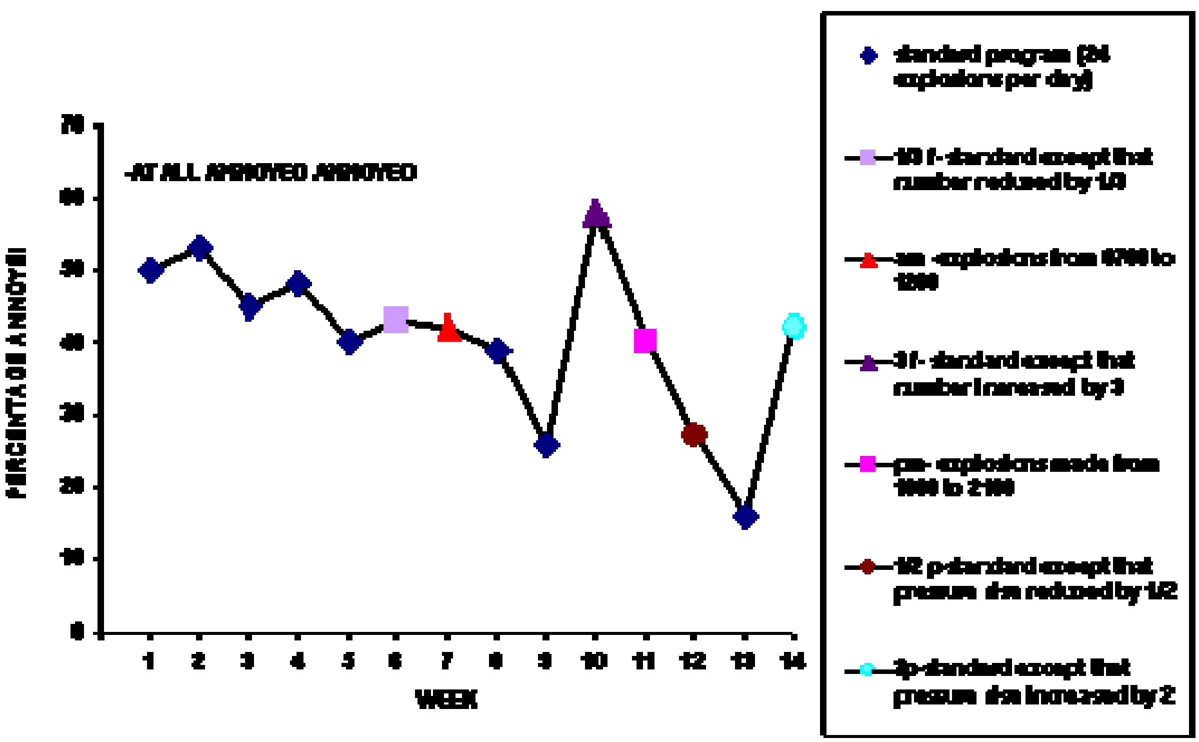


Figure 3-3 British Blast Study

House Rattles

In addition to the rapid growth in loudness as the decibel reading of a boom increases, the higher levels may lead to house rattles that cause annoyance to grow rapidly. In 1974, the Army funded Stanford Research Institute (SRI) to put a more precise number on the relationship between loudness, rattles, and annoyance. Working with the simulated noise and vibration of artillery blasts, the SRI found that the annoyance of explosions doubles for every 6.7-decibel increase in level (Young, 1976).

A study of all the noise complaints received by the Army in 1979 also demonstrated the importance of house vibrations (Luz *et. al*.). When complaints were separated into aircraft and weapons noise complaints, the following differences emerged (Table 3-2):

Item of Complaint	Weapons Noise	Aircraft Noise
Vibration	54%	10%
Damage to house	32%	4%
Falling Objects	14%	2%

Table 3-2 Complaint Responses to Weapons (impulsive) and Aircraft (transient) Noise

Ten years later, Army researchers reported on subjects in a test house exposed to simulated gun sounds. When the researchers added objects that rattled in response to the sound, the subjects reacted to the sounds as if they were 10 decibels higher (Schomer and Averbuch, 1989). Most recently, field studies of the annoyance of explosions and sonic booms conducted by the Army Construction Engineering Research Laboratories found annoyance to double with a 5 dB increase in level and here was a correlation between the growth of annoyance and the growth of window vibration (Schomer and Sias, 1998).

Time of Day

The importance of the fourth factor, time of day, is recognized in noise laws around the world by the use of penalties for noise made at night while people are sleeping. Not surprisingly, it has been found that not surprisingly people living near tank and artillery firing points are particularly annoyed by night fire. Friction develops between the military and civilians because nighttime training is particularly important for mechanized, armored, and attack helicopter units due to the tactical advantage from night vision devices. Compounding matters further, night training is inherently more irritating because low frequency sound travels farther when propagating through a nighttime temperature inversion.

3.1.1.6.4 THE C-WEIGHTED DNL

To take each of these four factors into account, the National Academy of Science's Committee on Hearing, Bioacoustics and Biomechanics (CHABA) provided the Department of Defense with a procedure known as the C-weighted day-night level. The final report of CHABA was published in 1981 and, since that time, the Army has assessed every training range firing guns of 20 mm caliber or larger using this procedure.

The C-weighted DNL (L_{cdn}) accounts for the four factors in the following ways:

- The procedure assesses the total noise dose over a period of time so that the amount of the noise exposure increases as:

    - o *The decibel level of the gun increases*

      OR

    - o *The number of shot increases*

      OR

    - o *Both decibel level and shots increase*

- Gun sounds between 10:00 PM and 7:00 AM are treated as if they are 10 decibels higher.

- Gun sounds are measured with the C-weighting of the sound level meter instead of the A-weighting. The C-weighting measures both audible frequencies of sound and the low frequencies responsible for house vibration while the A-weighting measures only the audible sound.

As stated at the beginning of this section, measuring a blast with C-weighting rather than A-weighting automatically increases the decibel reading. This is the first inherent penalty. But many experts disagree if there is a need for a second penalty for blast noise and, if so, what form that penalty should take. Through the years, technical experts have put forward four recommendations regarding a second penalty:

- <u>No Second Penalty</u> In the initial recommendation from the National Research Council (NRC), the L_{cdn} was calculated from a set of C-weighted SEL values in the same way as ordinary A-weighted DNL and the Schultz curve was used to evaluate the annoyance (NRC, 1977). Here there was no added penalty.

- <u>Sliding Penalty Added to CDN*L*</u> By 1981, experts working the NRC felt that the 1977 procedure underestimated the annoyance of the most intense exposures to sonic booms (NRC, 1981). To allow the DOD to interpret the L_{cdn} in terms of equal annoyance, the NRC's Committee on Hearing, Bioacoustics and Biomechanics (CHABA) provided a table showing the annoyance of an L_{cdn} of 62 dB to be the same as the annoyance of an L_{dn} (for aircraft) of 65 dB. Community noise exposure to an L_{cdn} of 70 dB was then declared to be as annoying as exposure to an L_{dn} of 75 dB and so on.

- Larger Sliding Penalty Added to CDNL In 1996, the NRC published a follow-up report recommending either adding a larger penalty onto the L_{cdn} or adjusting the CSEL to the annoyance of an ASEL prior to calculating the L_{dn}.

- Adjustment Added to CSEL This adjustment is based on experiments in which subjects compared the annoyance of different kinds of military sounds. These experiments identified a "point of subjective equality" between the annoyance of an aircraft flyover (measured by A-weighted SEL) and the annoyance of a blast (measured by C-weighted SEL). These experiments also showed that above the "point of subjective equality," the annoyance of a blast measured in CSEL increased at twice the rate of an aircraft flyover measured in ASEL. Specifically, the annoyance of blasts at levels above the "point of subjective equality" increase in annoyance by 2 decibels for every 1 decibel increase in measured CSEL.

3.1.1.6.5 ADJUSTMENTS FOR THE TIME PERIOD

In its 1974 "Levels Document," the EPA recommended that cumulative measures represent noise exposure over a 365-day year. There are, however, situations when a shorter period may be preferable. Prior to 1974, the Air Force and Navy had been assessing noise on the basis of the *average busy day*. The Army, which began its environmental noise program after 1974, followed the EPA recommendation of one year. At public meetings, a common complaint was that the Army was "hiding" the true extent of the noise level by averaging over the year and criticism was particularly intense at Army National Guard ranges where artillery might train intensely during the summer with months of silence during the rest of the year. In response, Army policy now allows for the noise dose to be calculated for different periods, e.g., *"busy day"*. So, for ranges that are used intermittently, calculating the noise dose over the time period of use will always give noise contours that are larger than the "annual average" (365 day) contour. In order to give citizens as much information as possible, Army commanders have the option of providing nose contour maps of a different assessment period. 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 use of "*average busy month*" DNL is appropriate when the op tempo is significantly different during certain peak periods of the year.

While the Army does not have a fixed procedure for calculating "*busy day*," the U.S. Air Force uses the following procedure:

- From the three busiest months of a year, compute the number of operations for the "average month."

- Compute the number of flying days in the average month by eliminating any day with operations less than one half of the number of the average day.

- Divide the number of total operations for the "average month" by the number of flying days to get the total operation for the average "busy day."

3.1.2 NOISE COMPLAINTS AND COMMUNITY ACTION

Community noise complaints are surely related to annoyance, but it is not a direct relationship. There are many situations where people are annoyed by noise but never complain to authorities. Even so, due to training on the good neighbor policy and general human nature, military commanders are usually interested in causing the public the least amount of irritation possible.

When complaints do occur, they are most commonly phone calls to the command section or Public Affairs office but others responses may include tort claims, threats of legal action, and formal lawsuits. Air Force and Army (Luz *et al*., 1983) studies have shown that complaints are most often triggered by unusually noisy events and there is also evidence that people are more likely to complain about a given level of noise if the ambient background in their neighborhood has been low prior to a change in operations. For instance, when a change in aircraft routes for New York/Newark metropolitan airports resulted in the DNL in Long Valley, New Jersey to increase from 42 to 49 dB, 6% of the population complained (Muldoon and Miller, 1989). Interestingly, this level would normally not be noticed in a typical urban setting but here it was noticeable in the "quiet" 42 dB ambient setting that Long Valley traditionally experienced.

Complaints, of course, make a problem obvious but commanders should not assume that the community is not annoyed just because there is not a good record of complaints registered with the base command or Public Affairs office. That there are no complaints may be because the community is not familiar with how to complain or where to voice their complaint. Strong interaction with the local community is a great conduit for discovering problem areas with noise before they blow up into a community uprising. It should be also noted that it is unreasonable and unwise for the military commander to expect zero complaints from the community. An examination of the Schultz curve indicates that at a DNL of 65 dB (which is what the DOD recommends as acceptable with residential housing) still has 13% of the population highly annoyed with the noise. Even if the noise was reduced to DNL 55 dB, 3-5% of the population will still be upset.

As stated above, complaints are usually triggered by short-term increases in the DNL or by single events that stand out as much noisier than the usual. The following case studies provide some information relevant to predicting complaints from military activities. (Please see Appendix A for a more detailed discussion of noise complaint guidelines.)

3.1.2.1 CASE STUDIES FROM NORWAY ON AIRCRAFT NOISE

In Norway, where regulators are concerned about both complaints and annoyance, zoning around airfields is based both on the average noise exposure and the maximum level of the three noisiest aircraft each week (Bugge *et al*., 1986). Based on experience at Scandinavian airports, land exposed to maximum levels of 105 dBA and higher is considered unsuitable for most buildings while land exposed to maximum levels of 100 dBA during the day or 90 dBA during the night is considered “unsuitable for dwellings, hospitals, churches, schools, etc.” New dwelling areas and other noise sensitive buildings are not recommended on land exposed to maximum levels of 95 during the day or 85 during the night.

3.1.2.2 CASE STUDIES ON GUN NOISE FROM THE NAVAL SURFACE WEAPONS CENTER, DAHLGREN, VIRGINIA

There are many reasons why people complain about gun noise. Some people just seem to be more physiologically reactive to intrusive sounds than others, and in the case of a few war veterans, gunfire can remind them of the horrors of the battlefield. Another variable is building construction because somebody living in a solid brick house with sealed windows won’t experience the rattles that someone living in a wood frame house with loose sash would experience. This interaction of personal variables and building construction further obfuscates the task of predicting complaints about gunfire.

When people do complain about gun sounds, they tend to complain about the most intense events. A simple way to measure the most intense events is with the peak sound pressure level. In 1976, engineers at the

Naval Surface Weapons Laboratory (NSWL), in Dahlgren, Virginia published a simple way of predicting whether people would complain about weapons testing (Pater, 1976). This method is shown in Table 3-3. The NSWL combined the data in this table in with a computer program that used meteorological data from a weather balloon in order to predict the levels that any particular gun would generate in “noise-sensitive” areas. The use of meteorological data was important because the weather has such a profound effect on the propagation of gun noise. In fact, the sound level a mile away from an explosion can differ by as much as 40 decibels from one day to the next simply because of the weather conditions

Predicted Sound Level, dBPeak	**Risk of Complaints**	**Action**
< 115	Low	Fire all programs
115 - 130	Moderate	Fire important tests. Postpone non-critical testing, if feasible.
130 - 140	High, possibility of damage.	Only extremely important tests should be fired.
> 140	Threshold for permanent physiological damage to unprotected human ears. High risk of physiological and structural damage claims.	Postpone all explosive operations.
Note: For rapid-fire test programs and/or programs that involve many repetitions of impulse noise; reduce allowed sound levels by 15 dBP.		

Table 3-3 Gun Noise Complaint Prediction Guidelines: Naval Surface Weapons Center

The guidelines developed at the Naval Surface Weapons Center have proved useful in predicting complaints at Aberdeen Proving Ground, Maryland as well. As documented in a paper by Luz and Eastridge (2001), most complaints at Aberdeen Proving Ground are associated with peak levels between 115 and 130 dBP.

3.1.2.3 CASE STUDIES FROM THE ENVIRONMENTAL PROTECTION AGENCY (EPA)

When the Environmental Protection Agency (EPA) published its recommendations on noise exposure in 1974, the focus was on predicting complaints not predicting annoyance (in fact, Dr. Schultz did not publish his curve of "percent high annoyance" until four years later). To demonstrate the value of their recommended procedure, the EPA analyzed a set of case studies in terms of five levels of community reaction:

- No reaction
- Sporadic complaints
- Widespread complaints
- Several threats of legal action
- Vigorous action

The EPA's graph showing the relationship between these case studies and DNL is reproduced in Figure 3-4. This graph established that communities are not likely to complain about an L_{dn} of 50 to 60 and justified the EPA's decision to set a residential L_{dn} of 55 as the long term goal of the national environmental noise management goal.

As noted, the data points in Figure 3-4 were "normalized" based on a set of corrections. These corrections, reproduced in Table 3-4, are traceable to the first Air Force Land Use Planning Guide (Stevens and Pictrasanta, 1957).

The most powerful correction in Table 3-4 is for background noise. This one adjustment covers a 20 decibel span with a correction of 10 dB given to noise made in a quiet suburban or rural community and a correction of minus (-) 10 dB given to noise made in a very noisy urban residential community. This is important for DOD planners because, since most military installations are located in rural areas where the background noise is generally low, it follows that complaints can be expected from relatively low levels of DNL.

Interestingly, low levels of background noise do not appear to result in people being more annoyed. Fields (1996b) analyzed 70,000 evaluations of 51 noise sources by over 45,000 respondents in 32 social surveys to determine whether residents' reactions to specific noise sources (target noises) are affected by other noise sources (ambient noises). Neither a strong nor statistically significant effect of ambient noise was found.

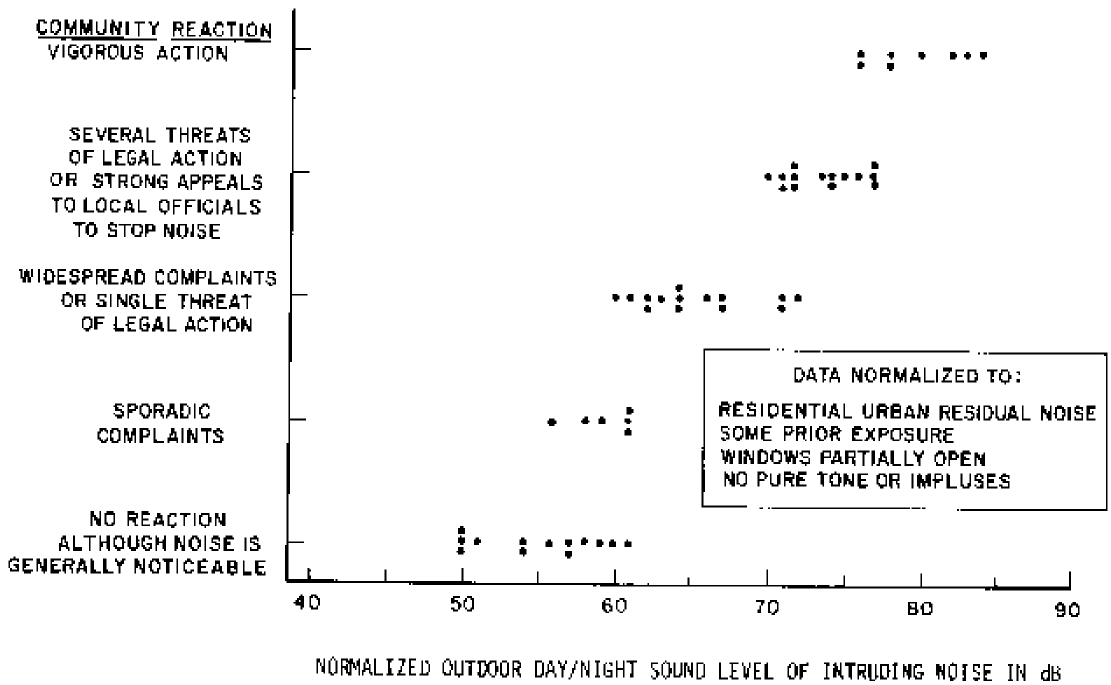


Figure 3-4 Community Response to the 55 Noise Environments in the EPA Study (EPA, 1974)

Table 3-4 also includes some corrections for differences in attitudes between communities. Attitudinal variables which may affect both annoyance judgments and noise complaints include (Fields, 1993):

- Awareness *"That bona fide efforts are being made to control the noise,"*
- *"Fear of danger from the noise source,"*
- *"Beliefs about the importance of the noise source,"*
- *"Annoyance with non-noise impacts of the noise source,"*
- *"General noise sensitivity"*

3.1.3 TASK PERFORMANCE AND ACTIVITY INTERFERENCE

The effect of noise on task performance depends on the task itself. Laboratory studies have failed to show reliable decrements in workplace performance at exposures below 95 dB. Nevertheless, noise in the work place may be fatiguing or distracting and the negative effects tend to increase along with the complexity of the task. An example of how task complexity increases the adverse impact of noise comes from a study of workplace exposure conducted in Israel (Melamed *et al*., 2001). This study, workers exposed to noise and had a complex job showed increases in blood pressure that were more than double those who were exposed to noise and had simple jobs. Blood pressure increases are a sign of stress.

Type of Correction	Description	Amount of Correction
Seasonal Correction	Summer (or year-round operation) Winter only (or windows always closed)	0 -5
Correction for Outdoor Noise Level	Quiet suburban or rural community (remote from large cities and from industrial activity or trucking)	+10
Measured in Absence of Intruding Noise	Normal suburban community (not located near industrial activity)	+5
	Urban residential community (not immediately adjacent to heavily traveled roads and industrial areas)	0
	Noisy urban residential community (near relatively busy roads or industrial areas)	-5
	Very noisy urban residential community	-10
	No prior experience with the intruding noise	+5
Correction for Previous Exposure & Community Attitudes	Community has had some previous exposure to intruding noise but little effort is being made to control the noise. This correction may also be applied in a situation where the community has not been exposed to the noise previously, but the people are aware that bona fide efforts are being made to control the noise	0
	Community has had considerable previous exposure to the intruding noise and the noise maker's relations with the community are good	-5
	Community is aware that operation causing noise is very necessary and it will not continue indefinitely. This correction can be applied for an operation of limited duration and under emergency circumstances	-10
Pure Tone or Impulse	No pure tone or impulsive character	0
	Pure tone or impulsive character present	+5

Table 3-4 Corrections for Normalizing DNL (EPA, 1974)

The same principle applies to noise exposures in DOD facilities and buildings (i.e., the more complex the task, the lower the noise exposure). In addition, it is very important to protect the sleep of the war fighter because fatigue can cloud decisions and increase the likelihood of accidents.

The guidelines in Table 3-5 should protect the occupants of military offices and workspaces from distractions due to noise and should be used by the base planner or environmental science officer to assess the suitability of a room for a particular use. It is further recommended that these same guidelines be used during deployment. For obvious reasons, sleeping areas should not be located next to runways, helipads, equipment pools, noisy generators or transportation routes.

Activity	**All Noise Sources L_{eq} (dBA)**	**Continuous Interior Sources * L_s (dBA)****
Sleeping	45	40
Other Residential Activities (Conversations, Radio, TV listening, etc.)	50	40
Classrooms, Libraries, Churches, Hospitals	50	40
Offices - Private, Conference	45	40
Offices/Work Spaces, Telephone Use Satisfactory	55	45
Work Spaces - Occasional Speech Communication or Telephone Use	60	55
Work Spaces - Infrequent Speech Communication, Telephone Use	70	60

*Typically, ventilation systems and mechanical equipment in near-continuous operations.
**The L_s value is given in terms of A-weighted noise level. The approximate noise criteria (NC) curve values are 8 dB less than the A-level values.

Table 3-5 Guidelines for Assessing the Suitability of Communication in Interior Rooms

3.1.3.1 SCHOOL ROOM ACOUSTICS

The guidelines for classrooms listed in Table 3-5 are for military classrooms such as those at armories or training bases. For school children, the American National Standards Institute (ANSI) has recommended a much more conservative limit of 35 dBA with a reverberation time of less than 0.6 seconds. Classroom learning is the one task for which scientific studies have demonstrated a potential for interference from noise. Also, not all children are adversely impacted by noise but the most susceptible are:

- The youngest
- Those with English as a second language
- Any child suffering from a hearing deficiency (including short term hearing loss from middle ear infections)
- Children starting with below average academic skills
- Children with Attention Deficit Disorder (ADD)

The more conservative ANSI guidelines take these more susceptible populations into account.

There is some evidence that high levels of noise in classrooms can even lead to physiological changes in children. According to Evans (1993), the three principal areas of impact are cardiovascular, cognitive, and personal control. Children chronically exposed to noise may suffer from increased cardiovascular activity and this increased activity may reflect direct sympathetic arousal and/or efforts to cope with the interfering effects of noise. Another study (Cohen *et al*., 1986) suggested that some of the effects of noise on children are not due to noise itself but rather to the coping processes children adopt to deal with noise. In the short term, the children can cope, but in the long term, they have lower motivation, lower reading scores, and less patience for solving difficult problems.

The ANSI standard on classroom acoustics applies to classrooms on the installation to the same degree as it applies to classrooms outside the installation. It should also be noted that contour maps of DNL, by themselves, cannot be used to determine whether a particular classroom is suitable for learning. For instance, if the DNL at an airbase were determined by aircraft departing before school starts and landing after school is ended, the exposure during the school day would be much less than indicated by the noise contour map.

3.1.3.2 ACTIVITY INTERFERENCE IN THE HOME

Surveys of people living near airports have shown that the most common disturbance of communication inside the house involves TV or radio reception. Table 3-6 shows that the most common complaint among those annoyed by aircraft noise is interference with speech communication (reproduced from Von Gierke and Eldred, 1993). Speech communication can also be a problem outdoors, particularly in areas of the country where people often grill or garden.

3.1.3.3 INTERFERENCE WITH COMMUNICATION

The most frequent disturbances listed in Table 3-6 concern understanding speech and the L_{eq} gives a rough indication of how well we can understand speech in a noisy environment (i.e., speech intelligibility.) In addition, acoustical engineers have a number of tools for making more precise estimates of speech intelligibility in noisy environments including the Articulation Index, Speech Transmission Index, and Speech Interference Level. These methods are particularly useful when there is a need to add noise to an open plan office to mask speech from one office to the next.

Activity	**% Disturbance***
TV/Radio Reception	20.6
Conversation	14.5
Telephone	13.8
Relaxing outside	12.5
Listening to records/tapes	10.7
Sleep	9.1
Reading	6.3
Eating	3.5

*Percent of people who were extremely disturbed by noise.

Table 3-6 Activity Disturbance in Residences Due to Aircraft Noise

Speech intelligibility is a function of:

- Signal to Noise Ratio (SNR), which is a ratio of the continuous speech level to the background level over frequency bands of interest
- Distance from the noise source(s)
- Distance from the speaker
- Speech level/Vocal effort
- Augmentation/Amplification of Speech
- Attenuation of the noise (e.g., Active Noise Reduction - ANR)

One of the simplest measures of speech interference is Preferred Speech Interference Level (PSIL). This is the arithmetic average of the sound pressure levels in the 500 Hz, 1,000 Hz, and 2,000 Hz octave bands which are the critical bands for voice communication.

3.1.4 HEARING LOSS

Long-term exposure to high noise levels has been shown to result in a noise-induced permanent threshold shift (NIPTS) or what is commonly known as hearing loss. Standards for hearing conservation have been based on studies of workers using the same equipment over a lifetime (such as jute weavers in Scotland) and other large, well controlled populations. Nevertheless, experts still disagree on the minimum noise level for protecting worker hearing.

The most conservative criterion is listed in the EPA Levels Document following the Congressional mandate to protect hearing with an "adequate margin of safety." It recommends a maximum 24-hour L_{eq} of 70 dB. In contrast, the OSHA regulation sets the 8-hour workday A-weighted exposure limit at 90 dB while military medical departments have taken a position between these extremes. Specifically, the Army Medical Department requires anyone who is working in an area where A-weighted exposure levels are above 85 dB to be enrolled in a hearing conservation program, even if the 85 dB exposure does not cover the whole workday.

In practice, hearing loss is rarely of concern in environmental noise assessments. Studies in the U.S. and Japan failed to show a decrement to hearing among people living near noisy airports or roads (Parnell *et al*., 1972, Ward *et. al*., 1976, Kabuto and Suzuki, 1979). An international epidemiological standard also confirms that no hearing loss would be expected from such exposures (ISO, 1989).

Putting this in perspective, to generate an 8-hour L_{eq} of 85 dB, over 9000 overflights per day at a SEL of 90 dB would be required (von Gierke and Eldred, 1993). Additionally, to eliminate attenuation from buildings, the exposed persons would have to be outside five days a week. And after 40 years of this exposure, the most sensitive 10% of the population would be expected to show a NIPTS of less than 10 dB. It is examples such as this that justify the decision by the military departments that hearing loss is not a consideration for people living near military airfields and training areas.

Nevertheless, there are some cautionary notes. The ISO standard reflects loss of hearing for audiometric frequencies of 6,000 Hz and below. In the 1960s, an otolaryngologist studied higher frequencies, comparing sensitivity at 16,000 Hz among African tribesmen living in natural quiet with that of people living in technological societies (Rosen, 1966). The tribesmen not only had superior high frequency hearing but also showed superior cardiovascular functioning. Rosen attributed their superior high frequency hearing to a good supply of oxygen to the inner ear resulting from a healthy diet and exercise. Could it be that natural quiet also protected their hearing? There is some limited (and highly controversial) supporting evidence from studies of German school children that living in areas routinely overflown by low-flying high performance military jets with ground levels in excess of 115 dB and rising at a rate greater than 30 dB/sec can effect hearing levels and induce ringing in the ears (von Gierke and Eldred, 1993). Are young children more sensitive because they haven't been exposed to excessively loud machinery? Future research is needed to answer these and other questions.

3.1.5 SLEEP DISTURBENCE OR INTERFERENCE

The effects of noise on sleep have long been a concern of those interested in providing a suitable noise environment in residential areas. Early approaches noted several background noise levels in people's bedrooms where sleep was apparently undisturbed. In the past, various levels were suggested as acceptable (ranging from 25 to 50 dB) but the bulk of the research on noise effects in the United States was conducted in the 1970s.

Many of these tests were conducted in a laboratory environment in which subjects, exposed to noises of various levels, were asked to indicate awakening verbally or by pushing a button. Other, more modern approaches have utilized brain wave recordings (EEG) to indicate stages of sleep, including awakening. Various stimuli have been used with particular focus on the transportation noise emanating from aircraft, trucks, cars, and trains. Early reviews of these studies made by Lukas (1975) and later by Goldstein and Lukas (1980) resulted in a relationship that predicted the percent of people awakened as a function of noise levels. Many, including the EPA, have used this relationship to predict sleep disturbance.

Due to the great variability associated with the Goldstein and Lukas data, Pearsons *et al.* (1989) completed one of the most comprehensive analyses of sleep disturbance studies to date. In their study, they compiled all relevant laboratory and field data, pointed out discrepancies, and suggested future lines of research. The data from this study were then used by the Air Force to develop an interim prediction algorithm based on a statistical adjustment to the data. This interim model predicts the percent of exposed population expected to be awakened (% Awakening) as a function of exposure to a single overflight and the noise metric used in the prediction is indoor Sound Exposure Level (SEL). Since outdoor and indoor noise reduction varies with types of building, construction techniques, and variable such as whether windows are open or closed, typical conditions have been defined. The EPA recommends attenuation factors for residential conditions of 17 dB for summertime (windows open) and 27 dB for wintertime (windows closed). In 1992, the Federal Interagency Committee on Noise (FICON) adopted the relation shown as the dashed curve in Figure 3-5.

Most reviews of published sleep disturbance studies suggest that factors such as habituation may have a significant effect in reducing sleep disturbance due to noise intrusions. Any increase in the precision of sleep disturbance predictions will depend on quantification of some of the non-acoustic factors such as amount of habituation (the length of time that the person has cumulatively been exposed to the noise), individual differences in sensitivity to sleep disturbance, adjustments for age and life-style factors, and individual interpretations of the meaning of the sound. And because the sleep disturbance curve published by FICON was based on both laboratory data (where subjects were in unfamiliar environments with unfamiliar noises) and field studies (where subjects were habituated to their surroundings and the noise), further research was conducted with subjects living in the vicinity of commercial and military airports. As expected, people who have habituated to their surroundings are less likely to be awakened by nighttime flights. Based on this research, the Federal Interagency Committee on Aviation Noise (FICAN) has recommended the sleep disturbance curve shown by the solid curve in Figure 3-5.

To review: When assessing sleep disturbance of routine activity in the vicinity of military airfields, the FICAN curve is recommended. But when assessing sleep disturbance from infrequent flights or noisier than usual flights at a military airfield, the FICON curve is recommended.

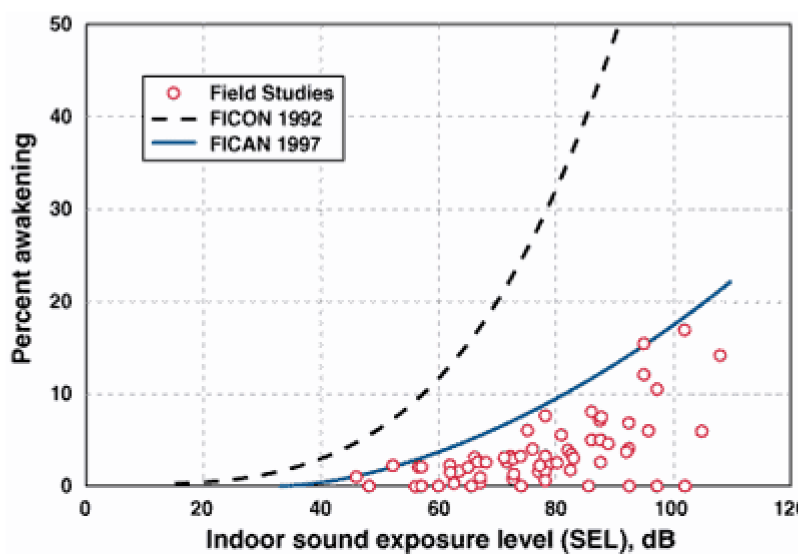


Figure 3-5 Sleep Disturbance Curve Recommended by FICAN

Now, in applying these curves to environmental noise assessments, it is important to recognize that they are predictions of whether noise from a passing aircraft will wake someone. Measurable changes in the brain and cardiovascular system will occur at lower noise levels so, if one defines sleep disturbance as “a statistically-significant change in the physiology of the sleeping person,” then guidelines must be set much lower.

For example, in the only published study of sleep disturbance from gunfire, Griefahn (1989) found the cardiovascular response to 120 mm main tank gunshots to be much larger during sleep than during waking. Consideration of these other effects has led to the following conservative guidelines published by the World Health Organization:

> *“When noise is continuous, the equivalent sound pressure level should not exceed 30 dB(A) indoors, if negative effects on sleep are to be avoided. For noise with a large proportion of low-frequency sound a still lower guideline value is recommended. When the background noise is low, noise exceeding 45 dB LAmax should be limited, if possible, and for sensitive persons an even lower limit is preferred. Noise mitigation targeted to the first part of the night is believed to be an effective means for helping people fall asleep (WHO, 1999).”*

Note that the recommended indoor level of 30 dBA is 15 decibels lower than the recommended level for military quarters listed above in Table 3-5. Again, the differences are due to the measures used to define sleep disturbance. If the goal is to eliminate any physiological arousal in the brain of the sleeper, then the WHO guideline is more appropriate. If the goal is to make sure that people aren’t awakened, the guidelines in Table 3-5 and Figure 3-5 are more appropriate.

NON-AUDITORY HEALTH EFFECTS

3.1.6.1 GENERAL

There has been considerable debate among environmental noise experts as to whether noise exposures below the level of hearing hazard result in other lasting health effects. According to Thompson (1996), early investigators tended to assume that noise produced direct effects and gave little attention to the individual differences in response to noise as a stressor or to the role of other stress producing factors. For various reasons, Thompson viewed most of the research prior to the 1980s as being “methodologically weak.” Thompson concludes that “the more methodologically rigorous studies tended to show no or weak associations between high noise and elevated blood pressure, heart disease, mental health problems, low birth weight, and birth malformations when major confounding factors were controlled.

It must be kept in mind, though, that these findings do not exclude the possibility that noise can result in an adverse health effect indirectly. For instance, it is widely known that the ability to control the circumstances of our lives is of particular importance to individual mental and physical health (see Shapiro *et al*., 1996, for a review). So, if someone feels "invaded" by noise and, as a result of this attitude, becomes angry, then the state of being angry is likely to result in high blood pressure (even if it is only temporary).

3.1.6.2 HEALTH EFFECTS OF HAZARDOUS NOISE

For hazardous noise ($\geq$ 85 dBA), there is substantial evidence that extended occupational noise exposure is a risk factor for high blood pressure (Lang *et al*., 1992). Fogari *et al*. (1994) matched workers on age, years employed, and body mass index and found significantly higher blood pressure in workers exposed to noise ≥85 dB compared to workers exposed to <80 dB noise. Similarly, Zhao *et al*. (1991) found the odds of hypertension increasing by 1.2 for each 5 dB increase in occupational noise level over a range of 75 to 104 dBA.

3.1.6.3 HEALTH EFFECTS OF TRAFFIC NOISE

At the lower sound levels associated with typical residential traffic noise exposure, health effects are minimal in adults but generally demonstrable in children. Babisch *et al*. (1999) studied 4,960 middle-aged men for ten years and they concluded that living adjacent to streets with high traffic noise levels was associated with an adjusted increase in relative risk for ischemic heart disease of 1.01 to 1.02 for each year in residence; a result that was only borderline significant ($p<.10$). Similarly, while working with 400 healthy Dutch citizens exposed to military aircraft and traffic noise and encompassing a group with subjects younger (ages 20 to 55) than the "middle aged" targets in the previous study, Pulles *et al*. (1990) were also unable to find noise-related differences in blood pressure.

However, with a younger sample of 192 healthy male and female citizens of Bonn, Germany, studied over three years, Otten *et al*. (1990) found a statistically significant increase in blood pressure among the females exposed to traffic noise greater than 63 dBA (L_{eq} from 0600 to 2200) as compared to control females living in an area with an L_{eq} less than 55 dBA. These results are tempered, though, by the fact that the increase among the noise-exposed males was marginal.

Among the youngest subjects studied, traffic noise definitely has a measurable effect. A study of 3 to 7 year olds exposed to 24 hour weighted traffic noise levels of 60 to 70 dBA near their kindergartens and homes showed with the higher sound levels a significantly increased blood pressure and decreased heart rate (Regecova and Kellerova, 1995). Blood pressure among the children in quiet homes did not rise with age as it did among children from the noisy areas. In another study, Wu *et al*. (1993) used deaf children as the control in studying children ages 7 to 12 attending school in areas where noise levels ranged from 60 to 75 dBA. Here, the deaf subjects had significantly lower blood pressure than the subjects with normal hearing after adjustment for age.

Other studies to consider:

- In addition to changes in blood pressure, children exposed to traffic noise at home are impeded in reading ability (Cohen *et al*., 1973).

- Muller et al. (1998) attributed the performance decrements which they found in traffic-exposed children (ages 8 to 10) to not sleeping well at night.

- Working with Austrian children, Evans *et al*. (2001) found better health in children exposed to average levels below 60 dBA than above 60 dBA.

3.1.6.4 HEALTH EFFECTS OF AIRCRAFT NOISE

Potential non-auditory health consequences of aircraft noise exposure which have been studied include birth defects, low birth weight, mental problems, cancer, stroke, hypertension, sudden cardiac death, myocardial infarction, and cardiac arrhythmia. As in the case for traffic noise, researchers have failed to demonstrate reliable adverse health effects of aircraft noise in adult populations but children, on the other hand, appear to be susceptible.

Studies of residential aircraft noise have produced contradictory results that are difficult to interpret. Early investigations indicated that morbidity due to hypertension was from 2 to 4 times higher in areas near airports than in areas located away from airports (Karagodina *et al*., 1969). And although Meecham and Shaw (1988) continue to report excessive cardiovascular mortality among individuals 75 years or older and living near the Los Angeles Airport, their findings have not been replicated (Frerichs *et al*., 1980). Furthermore, ecologic studies among residents of Nevada, where supersonic flight operations have occurred since 1969, demonstrate no evidence of a relationship between sonic boom exposure and mortality and morbidity (Anton-Guirgis *et al*., 1986). In fact, a trend analysis over time showed that noise exposure in the Nevada case actually increased over the years while there was a decline in age-adjusted mortality for all causes of death and inconsistent changes in age-adjusted cardiovascular, hypertension, and cerebrovascular disease rates.

Predictions of non-auditory health effects of residential aircraft noise cannot be made on the basis of available scientific information for the following reason: A valid predictive procedure requires: (1) evidence for a causal relationship between aircraft noise exposure and adverse non-auditory health consequences and (2) knowledge of a quantitative relationship between amounts of noise exposure and specific health effects (i.e.,, a dose-response curve). Because results of studies of aircraft noise on health are highly equivocal, there currently is no sound scientific basis for making adequate risk assessments.

The most substantial research showing a positive association between exposure to aircraft noise and adverse health effects are the surveys of Knipschild and colleagues in the vicinity of Amsterdam Schiphol Airport (Knipschild, 1977; Knipschild and Oudshoorn, 1977). Significantly higher sex- and age-adjusted prevalence rates of hypertension were found in people from a high aircraft noise area than in individuals in a low noise area. The finding of a possible dose-response relationship strengthens the plausibility of the association. However, the response rate in Knipschild's study was only 42% and no risk factors for hypertension other than age and sex were controlled thus leaving the question up in the air.

The critical question is whether observed positive associations are causal ones. Cross-sectional studies such as those reported above cannot establish the time precedence of noise exposure since the noise exposure was measured at the same time as the health effect (Brown *et al*., 1975). Also, these (and other related studies) cannot be considered definitive because of insufficient sample sizes and other methodological problems.

For the most susceptible age group, children, effects of aircraft noise on blood pressure appear to be less significant than found among children exposed to traffic noise. A cross-sectional study of school children near Los Angeles Airport reported statistically significant but small changes in blood pressure (Cohen *et al*., 1980) and Morrell et al. (1998) found no effect of noise on blood pressure among children living within 20 km of Sydney Airport. Finally, Hygge *et al*. (1998) reported a marginally significant increase in resting blood pressure ($p<.06$) among children in a school where noise levels from the Munich airport increased to an Leq of 65 dBA from 53 dBA. All the same, decrements in school performance were observed in both the Los Angeles and Munich airport studies as well as in an earlier, less-controlled study at JFK and LaGuardia airports (Green *et al*., 1982) so this issue remains unresolved as well.

Complicating matters further, although aircraft noise does not have much of an effect on blood pressure in children, it does appear to increase the body's production of stress hormones. As shown by the Munich Airport study, children subjected to the increase in aircraft noise had elevated urinary neuroendocrine levels ($p<.001$). This finding among children parallels a finding among adults exposed to low-level military flights (75 m minimum altitude). Findings show that, although there was no difference in blood pressure between adults living in a quiet area, in a 150 m minimum altitude area, and the 75 m minimum altitude area, secretions of stress hormones was significantly higher in the 75 m low flight area (Schulte and Otten, 1993). But whether or not these secretions have an impact on longevity is also yet to be determined.

3.1.7 IMPACT ON THE ENJOYMENT OF NATURAL SOUNDSCAPES

In the late 1980s, some members of the public became concerned about the noise of tourist aircraft, particularly helicopters, in national parks and wilderness areas. Congress directed the Department of Interior to look into this issue through the National Park Service Overflights Act of 1987 and Public Law 100-91. In their report on natural quiet (U.S. Department of the Interior, 1995), the Park Service introduced the metric of audibility as a way of assessing the impact of transportation noise on natural quiet. But the use of audibility as a metric requires dramatically lower military noise levels than does DNL due to the fact that, while a L_{eq} of less than 65 dBA during the day is considered acceptable for a residential area, the daytime L_{eq} in the quietest national parks can be lower than 20 dBA.

At the time this manual was being written, the Federal Aviation Administration, the National Park Service, and the DOD were engaged in discussions about the protection of natural soundscapes and it is expected that policy will evolve over time. In the meantime, trainers must be concerned with the potential effect that overflights in our national parks and wilderness areas may have on the wildlife and visitors. I follows that, while overflights in these areas may not be avoidable, low altitude flights over sensitive areas are unwise. It is best to fly offset from known sensitive areas and an open dialogue with the local park and/or forest staff can help to resolve any potential conflicts.

3.2 IMPACT ON ANIMALS

There are several reasons for military trainers and operations officers to be concerned about the impact of noise on animals. First, many military installations are located near ranches, farms, and other livestock operations and through the years, a number of tort claims have been filed alleging loss of domestic animals due to military noise. Second, many military installations have become refuges for threatened and endangered species (TES). And U.S. Fish and Wildlife officials are legally obligated to protect these populations from any danger, including detrimental levels of noise. A third reason, which applies primarily to the Navy, is to meet the requirements of the Marine Mammals Protection Act of 1994 (MMPA).

Because each species has a unique auditory sensitivity, it is not feasible to extrapolate to animals any effects noise may have on human annoyance or health. In some cases, levels of noise judged intolerable by people do not bother animals. But in other cases, animals are adversely impacted by noise judged otherwise innocuous by people.

In determining the effect a noise may have on a particular species, one of the first questions that must be asked is, “How well does the species of interest hear the noise.” Frequently, that question can be answered by consulting a compendium of animal audiograms such as that published by Fay (1988).

Still, even if a species can hear the noise, it may not necessarily react to it. The reaction an animal will have to the noise is specific to each species. The onset rate will cause animals to react in different ways (from no response to a fight-flight, panic response) but over time and with enough repetitions, most animals do habituate to the noise. The best noise measures to assess the impact on animals are the single event descriptors of SEL and onset rate.

The scientific literature on how different species react to noise is scattered over a wide array of journals, contractor reports, and government reports. As stated in an Army review of this literature, it consists of “a preponderance of small, disconnected, anecdotal, or correlational studies as opposed to coherent programs of controlled experiments” (Larkin *et al*., 1996). In an attempt to bring order to this patchwork of studies, Air Force and Army researchers have taken two actions:

- They have collected all the animal effects literature into the International Bibliography on Noise (IBON). The IBON is a dynamic document with both Air Force and Army contributing to upgrades and it is available as a CD or for download for the United States Army Center for Health Promotion and Preventative Medicine (USACHPPM).

- They have grouped the various research findings under categories known as “animal models.” An “animal model” is a grouping of species with comparable auditory sensitivity and comparable reactions to noise. A few examples of “animal models” are provided in the following case studies and the IBON may be consulted for additional information about other animals.

3.2.1 LARGE DOMESTIC ANIMALS (LIVESTOCK)

Concerns have been expressed that overflights can damage livestock by causing panics that result in trauma, by inducing abortions or other reproductive losses, and by compromising stock marketability. Yet, the published literature does not contain conclusive evidence for any serious effect except trauma resulting from panic reactions.

Panic reactions are the most important cause of losses and 59% of the 137 claims brought against the USAF from 1956 to 1988 for alleged damage to livestock were for losses incurred in panic reactions with the costliest awards for escapes of valuable animals. The most useful experimental studies consisted of controlled exposures to helicopter and fighter aircraft overflights at the University of Hannover in West Germany during the 1980s (Erath, 1984; Kruger, 1982; Beyer, 1983; Heicks, 1985; Heuwieser, 1982). In these studies, cattle and horses were exposed to extremely high levels of aircraft activity; more than 90 overflights ranging in sound level from 85 to 130 dBA at altitudes below 100 m over a two-month period. The livestock were naive at the time of first exposure and some were pregnant. Although the sample of animals was small, these studies provide the best evidence of the low potential for damages and losses on a per-animal basis.

3.2.2 DOMESTIC FOWL

Birds that are considered domestic fowl include chickens, turkeys, ducks, geese, and other birds commercially grown for meat consumption or egg production. While negative effects of noise exposure on fowl are rare they can be serious under the right set of conditions.
There is little disagreement that mortality and morbidity can occur during panic reactions induced by overflights. And, while changes in meat marketability and egg productivity are theoretically possible, scientific documentation of these losses is lacking so only the data on panic responses are sufficient to develop models of effect.

Panic piling and crowding can be provoked in poultry experimentally by exposing them to sudden, intense noise. The acute portion of the reaction (active piling) ceases as soon as the stimulus ceases and all birds return to normal activity within a few minutes. Still, panic is a problem because, when confined birds pile-up, some may die immediately and others may inflict or incur and nonfatal injuries (usually on the back). Any deaths as a result of injuries, heart attacks, or overheating due to the panic situation generally occur within 72 hours of the incident and it should be noted that experiments have shown the incidence of losses during such a panic is likely to be very low under most conditions. There have been only two deaths (out of hundreds of exposed birds) in controlled experiments with high levels of noise.

The Air Force has conducted experiments with poultry on working farms (such as Milligan *et al*., 1983) and one finding from these experiments is that even relatively naive flocks of thousands do not automatically panic. But once a panic occurs, losses may be large, with housing conditions, species, and temperature being the most important predisposing factors. Based on experimental studies and interviews with growers, panic crowding occurs only in naive birds and is extinguished within five exposures to a startling stimulus (and usually within two exposures). The threshold for response (where a few birds start to respond) ranges from approximately 75-85 dBA. When the level reaches 100 dBA, 100% of the birds respond with flying and crowding. This relation has been determined using data on the responses of both wild raptors (Awbrey and Bowles, 1990) and turkey poults (Bradley *et al.*, 1990).

For large flocks, an estimate of loss rates can be gleaned from the claims brought against the Air Force by growers. From 1956 to 1988, there were 100 recorded claims against the Air Force for alleged damages to domestic fowl of which 55% were for losses in panics. The most serious loss in a substantiated claim was 38% of a flock of mature tom turkeys during a heat wave and this has been taken as the worst-case estimate of impact.

3.2.3 RAPTORS

Although panics induced by aircraft may cause mortalities in captive birds, such mortalities have never been detected in wild birds. Nonetheless, losses of eggs and young are possible when parents panic and subtler effects on nest establishment and parental care may also occur (Awbrey and Bowles, 1989). At present there are a few limited studies that show the influence of aircraft on the tendency of adult birds to change nests (nest fidelity) and the numbers of young fledged per active nest. There is a fairly well-established correlation between human intrusion (people near the nest site) and nesting losses in birds (*e.g.*, Anderson, 1989); however, any correlation that may exist between aircraft overflights and losses has never been demonstrated. This may indicate that there is no correlation between overflights and losses or it may be a consequence of inadequate sample sizes.

At present there are a few limited studies that show the influence of aircraft on the tendency of adult birds to change nests (nest fidelity) and the numbers of young fledged per active nest. It is unclear that the tendency to change nests has any effect on reproductive output (Platt,

1977) so the number of young fledged per nest is considered the most important measure. There is a fairly well-established correlation between human intrusions and nesting losses in birds (Anderson, 1988) but any correlation that may exist between aircraft overflights and nesting losses has yet to be demonstrated.

Most of the quantitative studies of aircraft effects have dealt with raptors (hawks, eagles, and falcons). These studies have found a slight decrease in reproductive success of exposed nests relative to "control" nests, both in numbers of successful nests and numbers of young fledged. The deviation between observed and expected reproductive success has been less than 18% in every case, a difference not likely to be significant given the typically small sample sizes, and none of the over 200 nests observed in all the studies combined experienced losses of young directly attributable to the overflights, either from panic flight or from abnormal parental behavior. Therefore, the cause of the decrease in success is unknown, and losses in panics must be considered rare. Losses are not due to exposure, since only 4% of parents actually fly off the nest in response to close approaches by aircraft, and when they do, they typically are gone for less than one minute (under normal circumstances parents routinely leave their nests for episodes of more than one minute). Consequently, the cause of the decrease in success is unknown and losses in panics must be considered rare.

Few studies have documented the threshold distance that causes birds to flush in response to noise disturbance events. In those studies that reported stimulus distance, it was rare for birds to flush when the stimulus distance was greater than 60 m (Carrier and Melquist 1976; Edwards et al. 1979; Craig and Craig 1984; Pater et al. 1999; Delaney et al. 1999, 2000, 2001). Similar findings were reported by Carrier and Melquist (1976) for Osprey (*Pandion haliaetus*), and by Ellis (1981) for Peregrine Falcons. Many disturbance studies report that animal response increases with decreasing stimulus distance (Platt 1977; Grubb and King 1991; McGarigal et al. 1991; Stalmaster and Kaiser 1997), though only a few studies have experimentally tested this relationship (Delaney et al. 1999, 2000, 2001; Pater et al. 1999). Delaney et al. (1999) found that the proportion of owls flushing in response to a disturbance was strongly and negatively related to stimulus distance and positively related to noise level. Spotted owls were not observed flushing when noise stimuli were > 105 m from owl locations. Delaney et al. (1999) also reported findings for Mexican Spotted Owl (*Strix occidentalis lucida*) response to military helicopter activity and chain saws, observing that chain saws elicited a greater flush response rate than helicopters at comparable distances and noise levels.

Snyder et al. (1978) reported that Snail Kites (*Rostrhamus sociabilis*) did not flush even when noise levels were up to 105 decibels, A-weighted (dBA) from commercial jet traffic. This result was qualified by the fact that test birds were living near airports and may have habituated to the noise. Edwards et al. (1979) found a dose-response relationship for flush responses of several species of gallinaceous birds when approach distances were between 30 and 60 m and noise levels approximated 95 dBA.

One study that examined the effects of low-level jets and sonic booms on nesting peregrine falcons (*Falco peregrinus*) and other raptors was in Arizona (Ellis 1981). Though birds were noticeably alarmed by the noise (82-114 dBA) the data showed no associated reproductive failure. In addition, no significant changes in heart rate were noticed.

One of the most comprehensive studies of the response of a bird species, the prairie falcon (*Falco mexicanus*), to impulsive noise was performed by Anthonie M. A. Holthuijzen (Holthuijzen 1989) for the Idaho Power Company, the Bureau of Land Management and the Pacific Gas and Electric Company. The behavior reaction to the impulsive noise was evaluated by the type of pre-event behavior compared with post-event behavior. The falcons were exposed to peak sound levels between 129 and 141 dBP. Each aerie was exposed to an average of 90 events over a period of 62 days.

Common pre-event behaviors included perching, incubating, brooding, flight and preening. The falcons usually responded to the impulsive noise by continuing their pre-event behavior or by a short flight followed by their pre-event behavior. During the study, there was no evidence of habituation to the noise. However, the occupancy of the nesting areas exposed to the noise remained the same the year following the impulsive noise events. From this study, it appears that the prairie falcon is sometimes annoyed by the impulsive noise events, but not annoyed enough so that they will permanently abandon an established nesting area with a readily available food supply.

In north central Michigan the responses of six pairs of bald eagles (*Haliaeetus leucocephalus*) to over 700 events of potentially disturbing human activity were recorded (Grubb, et.al. 1993). The highest frequency of response was from anglers, automobiles, and gunshots. The authors suggest that the wide disparity in response frequencies for noise types (0 percent for artillery, 76 percent for gunshots) implies that eagles near military bases habituate to distant artillery noise. Eagle responses to gunshots and sonic booms were 52 percent and 63 percent, respectively, in Arizona (Grubb and King 1991).

The U.S. Army Aberdeen Proving Ground (APG) supports one of the largest bald eagle concentrations on the Northern Chesapeake Bay. The testing of large caliber weapons (155 mm howitzer) and detonation of large explosive charges (greater than 300 lbs.) at U.S. Army Aberdeen Proving Ground is creating significant noise, and producing concerns on the potential effects on bald eagles. Systematic observations on potential influence of noise on bald eagles were made from November 1993 through December 1995. The study indicated that most bald eagles show no activity following weapons-testing noise events (Russell and Lewis 1996)(Brown et al. 1999) thus, no significant behavioral reactions to loud (>110 dBP) noise events at nests and roosts. Bald eagle nest success and productivity from 1990-1995 was comparable for APG and adjacent areas in Maryland, imply that weapons-testing noise did not reduce overall reproductive performance of nesting bald eagle population on APG.

3.3 IMPACT ON STRUCTURES

3.3.1 VIBRATION FROM LOW-FREQUENCY SOUND

The sounds of aircraft operations and impulsive weapons may result in vibration of a structure and, on rare occasions, in structural damage. This section addresses the possibility of structural damage.

Damage is usually associated with sonic booms produced by supersonic operations or by intense overpressures from high explosive artillery, bombs, or combat engineer demolitions. Generally, sound from military training does not affect natural structures. There are instances where the U.S. Forest Service, mountain states and ski resorts have, on occasion, used old military weapons for avalanche control, but damage to more-permanent natural structures is undocumented. For this reason, the available research (most of which concerns supersonic flight) has emphasized man-made structures in two major groupings:

- Conventional structures. Buildings that normally are occupied including most homes, churches, schools, hospitals, office buildings, and businesses.

- Unconventional structures. Include all other man-made structures. The category of unconventional man-made structures covers a multitude of new and old applications. Old applications encompass prehistoric and historical resources while new applications include structures such as antenna towers (which are facilities that tend to be very sensitive to noise and vibration).

In general, the most sensitive parts of conventional structures are the windows, followed by the doors, and finally the floors. For residential wood frame construction, structural elements are most sensitive to sound energy between 1.0 and 30 Hz and occupants will begin to notice vibrations at sound levels far below the intensity needed for structural damage. Figure 3-6 shows the sound pressure levels sufficient to cause perceptible vibrations (Hubbard, 1982).

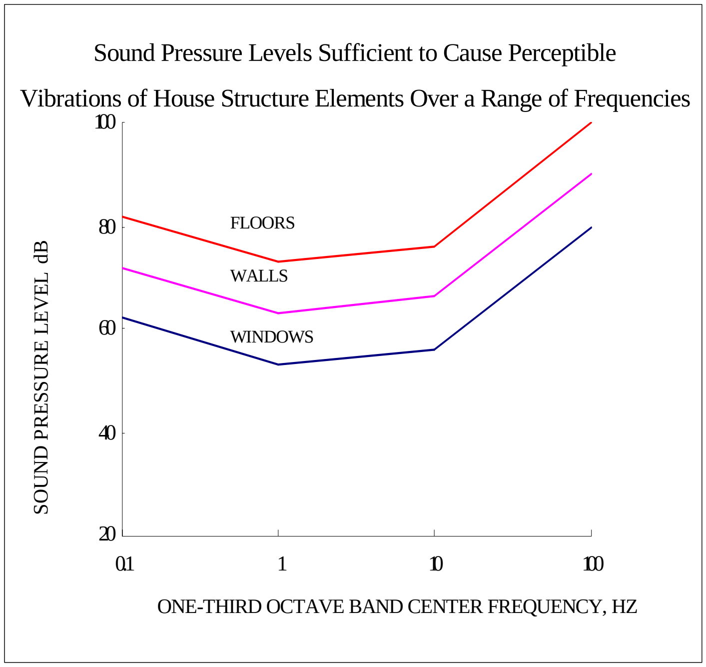


Figure 3-6 Sound Pressure Levels Sufficient to Cause Perceptible Vibrations in a Wood Frame House

Low levels of house vibration may result in “nuisance effects” such as the clattering of dishes on a shelf, rattling of glass in a chandelier, or shifting of a picture frame on the wall. Complicating matters is the fact that typical U.S. residential construction is particularly prone to rattles from low frequency sound (Wyle, 1983).

Fixed wing aircraft do not, as a general rule, generate enough low frequency energy to induce vibrations but exceptions include engine run-ups prior to takeoff and the levels inside engine test cells or “hush houses.” Helicopters, on the other hand, are quite likely to generate vibration during routine flights (TNO 1994). According to the TNO study, “helicopter operations may also produce vibrations of buildings and rattling of windows, ceiling tiles and objects in buildings.” Most effective at producing vibrations are the low frequency spectra of sonic booms and large weapons (i.e., weapons of caliber larger than 30 mm).

3.3.2 GROUND-BORNE VIBRATION

When people experience house vibration from explosions, they tend to attribute it to ground-borne vibration. While it is true that certain military training (such as the use of cratering charges by military engineers) will cause ground vibrations, the explosive weight is generally not large enough and the distance between civilian homes and the explosion not short enough to result in ground-borne vibrations.

Engineers use a calculation known as *scaled distance* (see explanation below) to decide whether ground-borne vibration is a problem and studies of vibration caused by coalmine detonations (Northwestern University, 1981) indicate that the ground-borne vibration dominates house vibration only at scaled distances of less than 50. At scaled distances greater than 50, the airborne vibration dominates. The Bureau of Mines demonstrated this relationship for military explosions in an 18-month study conducted at the McAlester Army Ammunition Plant in 1988 (Siskind, 1989).

> *Explanation of* **scaled distance***: The scaled distance is equal to the distance from the source to the receiver, in feet, divided by the square root of the explosive weight in pounds. For a 100-pound charge, a distance of 500 feet is required for the scaled distance to equal 50. That is, for a 100-pound charge, the ground-borne vibration is the dominant cause of house vibration if the house is located less than 500 feet from the detonation point. At distances greater than 500 feet, the airborne sound wave is the dominant cause of vibration*.

If there are ground-borne vibrations, people can typically perceive them as low as 0.08 to 0.20 inches per second (Argonne, 1993). Table 3-6 shows how people's perception of ground vibration rises rapidly as the level of ground-borne vibration increases.

Ground Vibration Response	**(inches per second)**
Perceptible	0.08
Noticeable	0.20
Unpleasant	0.38
Disturbing	0.80
Objectionable	1.30

Table 3-7 Human Responses to Building Vibration Levels

In terms of structural damage, the maximum ground-borne vibration level recommended by the U.S. Bureau of Mines to prevent threshold damage is 0.5 inches per second (Bureau of Mines, 1980). The threshold level at which minor structural damage may begin to occur in 0.01 percent of structures is set at 2.0 inches per second. To put these numbers in a military perspective, the maximum predicted ground vibration at 12.5 kilometers for a 105-mm howitzer round detonating in the impact area is

0.00042 inches per second. For a 500-pound bomb, the maximum ground vibration is 0.0033 inches per second.

3.3.3 DAMAGE FROM AIRBORNE SOUND

As shown in Table 3-7, reproduced from Siskind (1989), homeowners become concerned about structural damage at levels far below those capable of actually causing structural damage.

Vibration Response	Peak Sound Level (inches per second)	(dBP) (re: 20 μPa)
Concern by Homeowners about Structural Rattling and Possible Damage	0.1	120
Glass and Plaster Cracks	0.5	134
Worst Case* Structural Damage to Lightweight Superstructure	>2.0	175
Damage to Concrete	>4.0	185

*Worst case = Poorly fitted loose window glass and stressed plaster walls.

Table 3-8 Response to Airborne Vibration Levels

Considerable knowledge exists on natural forces and mechanisms that cause structural damage including (U.S. Air Force, 1990):

- Ratio of inside to outside surface and air temperatures.
- Range of inside and outside humidity. Temperature and humidity influence the amount of shrinking of wood frame members, which is a major source of cracking of interior surfaces.
- Intensity, duration, and direction of wind.
- Uneven settling of building foundation.
- Room volume and wall and ceiling area (high walls and cathedral ceilings). The larger the surface area of a wall or ceiling, the more likely it is to crack from expansion and shrinkage.
- Orientation and partial shading of wall from sunlight (uneven heating causes uneven expansion of walls).

- Type of skin, frame, exterior materials, and interior finish.
- History of patching.
- Presence of water leaking from or condensing on interior pipes and from external sources into building structure.

When structural damage does occur, it is almost always window breakage. There have been several studies of the probability of window breakage and the results from one study (FAA, 1976) are summarized in Table 3-8.

Pressure (psf)	**Sound Pressure Level, (dBP)**	**Probability of pane-events breakage* (panes per million)**
1	128	0.28
10	148	5,000
100	168	380,000

*Number of window panes per million window panes broken for each event

Table 3-9 Probability of Window Breakage

With the exception of window breakage, booms less than 11 psf should not damage "building structures in good repair" (Clarkson and Mayes, 1972). At higher levels, the most common form of structural damage from vibration caused by sonic booms and heavy weapons firing consist of cracks in interior wall/ceiling surfaces. As such, a number of guidelines have been developed for the identification and quantification of damage due to these sources. The maximum safe predicted levels for representative building materials on interior walls and ceilings are listed in Table 3-9. For reference, "maximum safe level" is defined as a 99.99 percent confidence that damage will not occur (U.S. Air Force, 1990).

According to the Property Claim Services and Engineering and Safety Service of the American Insurance Services Group (1990) experts generally agree that, if airblast causes any damage, it will first manifest itself in the form of broken window glass. Damage such as plaster cracking is very rare, but when it occurs it is always accompanied by window breakage and occurs almost simultaneously.

One of the principal causes of the cracking plaster in residential construction is the shrinking and expansion of lumber as the atmospheric humidity changes over a period of time. Another cause of plaster cracking is the settling of the foundation. Although foundation cracks are

Material	Peak Pressure (lbs per sq ft) for		Peak Sound Level (dBP) for	
	Minor Damage*	Major Damage**	Minor Damage*	Major Damage**
Plaster on wood	3.3	5.6	138	142.6
Plaster on Gyplath	7.5	16	145.1	151.7
Plaster on Expanded metal Lath	16.0	16.0	151.7	151.7
Plaster on Concrete Block	16.0	16.0	151.7	151.7
Gypsum Board (new)	16.0	16.0	151.7	151.7
Gypsum Board (old)	4.5	16.0	140.7	151.7
Nail Popping (new)	5.4	16.0	142.2	151.7
Bathroom Tile (old)	4.5	8.5	140.7	146.2
Damage Suspended Ceiling (new)	4.0	16.0	139.6	151.7
Stucco (new)	5.0	16.0	141.6	151.7

* Minor damage includes small (less than 3 inches) hairline crack extensions and pre-damaged paint chipping
** Major damage includes falling plaster and tile.

Table 3-10 Maximum Safe Predicted Levels

commonly thought to be caused by vibration, they are usually the result of the wall's inability to withstand the external earth pressure without deflection. And when deflection occurs cracks are bound to appear.

The third cause of plaster cracking is water leaking from interior pipes, or through windows, roofs, walls, or foundations. The United States Department of Interior, Bureau of Mines, has published a list of 40 causes of cracks in walls and ceilings (1984).

3.3.4 DAMAGE TO UNCONVENTIONAL STRUCTURES FROM SONIC BOOMS

The Air Force has also studied the effects of sonic booms on unconventional structures such as historic and prehistoric structures (U.S. Air Force 1990). One particular structure studied was the McDonald Range House, a historic landmark at White Sands Missile Range, New Mexico. At this structure, sonic booms were monitored with five noise sensors and nine vibration sensors and photographic documentation of the Range House was taken before and after the monitoring.

During the monitoring period, 17 sonic booms were measured at the McDonald Range House. The unweighted peak levels of these sonic booms averaged 123 dBP and varied between 112 and 131 dBP. The accelerations measured by the vibration sensors varied between 0.001 and 1.215 gravities which are approximately equal to velocities of 0.005 to 6.0 inches per second. In the end, the photographic documentation showed no noticeable visual damage.

These high velocities, when compared to the levels listed in Table 3-9; show that the guidelines are conservative. The lack of evidence of damage is consistent with the low probability of sonic-boom damage predicted for this type of structure. However, since the Ranch House is over 50 years old, it is possible that a six-week monitoring period may be too short to establish any evidence of structural damage from sonic booms that occurred during the test period. True degradation caused by sonic booms (e.g., the development of new cracks) may only appear after a much longer period of exposure. There is also the potential that the previous explosive tests and sonic booms have already damaged the weakest components of the structure and the Ranch House was fully stress-relieved before this monitoring.

While additional experiments must be conducted to answer definitively the effects of sonic booms on unconventional structures, these results indicate that major damage is fairly improbable.

3.4 IMPACT ON PROPERY VALUES

Fidell *et al*. (1996) conducted a study that undertook both a statistical and geographical analysis of the potential effects on the sale prices of residential properties that are exposed to aircraft noise from the flight operations of Langley (Virginia) and Davis-Monthan (Arizona) Air Force Bases.

Although site-specific analyses can provide answers to the question “Does military aircraft noise affect residential property values at a particular Air Force base?,” the great number and diversity of factors affecting real estate markets in different times and places make it unlikely that a rigorous universal answer can be found to more general forms of the question. Arriving at any general conclusion regarding real estate is difficult for the following reasons:

- Property values are affected by many factors that fluctuate greatly by area and time period for reasons completely unrelated to aircraft noise exposure (e.g., economic opportunities or lack-there-of).

- A full demonstration of the effect of aircraft noise on property values requires an evaluation of how a community would have developed had an airbase not been constructed nearby.

- Zoning regulations play an important role in property values. If the land surrounding an airbase is zoned for residential use, the property values may decline. However, if the land is zoned for commercial use, the property values will increase (Fidell *et al*., 1996).

Regrettably, without an unambiguous way to define the effect of noise on property values, the decision is often left to the courts. An example of this is Westover Air Force Base in western Massachusetts.

Westover served as a bomber-training base and port of embarkation and debarkation during World War II. In the 1950's, the base was vital in transporting freight and passengers to forces in Korea (primarily with C-47 and C-54 propeller aircraft) and from 1955 to 1974, it was a major base of operations for the Strategic Air Command, using B-52 bombers that generated an SEL of 121 dB at 1000 feet under the takeoff. Later, from 1974 to 1987, operations shifted to the C-130 with an SEL of 91 dB at 1000 feet under the takeoff and then, in 1987, noise levels shifted up once again with the stationing of the C-5A with an SEL of 112 dB at 1000 feet under the takeoff.

With the arrival of the C-5A, community response was swift and coordinated. The neighbors argued in their 1987 lawsuit that the military had underestimated its noise impact on the community. The court ultimately found that the USAF had indeed made a good faith effort to estimate the noise but decision still allowed for citizen recourse if the Environmental Impact Statement estimated noise impacts were exceeded. Thus, litigation continued and in 1994 resulted in a $1.5 million settlement to 42 families who suffered losses to their property values.

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CHAPTER FOUR

MILITARY NOISE SOURCES

DOD installations generate a wide variety of noise from sources including jet and propeller aircraft, helicopters, small arms fire, sonic booms, large explosions, and large weapons. For each source, there is a preferred metric for assessing annoyance and unique methods for mitigating impacts. The purpose of this chapter is to describe the important acoustic features of the DOD's noise sources, explain the reasons behind the choice of metrics, and alert the reader to ways of mitigating each source to avoid complaints. A more complete discussion of mitigation will be found in Chapter 7.

When dealing with military noise sources, there are some commonly accepted definitions we use to give the reader a frame of reference. When talking about the direction of a noise, we always refer to the center of the noise source as the origin of a circle from which the noise would propagate outward. The front of the source (the direction the operator is facing) is referred to as the "0 degree" point and angles increase clockwise around the noise source. So, since the center of an aircraft is where the engines are located, that would be "0 degrees;" for a gun, it is the muzzle. And thus a receiver standing perpendicular to an aircraft on the right side would be at 90 degrees and on the left side, would be at 270 degrees (see Figure 4-1).

For a helicopter, these angles are particularly important, because the noise field around helicopters is asymmetrical. On the other hand, for a gun, the noise at 90 degrees will be the same as at 270 degrees, and the maximum angle is 180 degrees or what would be the direction of fire (and thus the loudest noise).

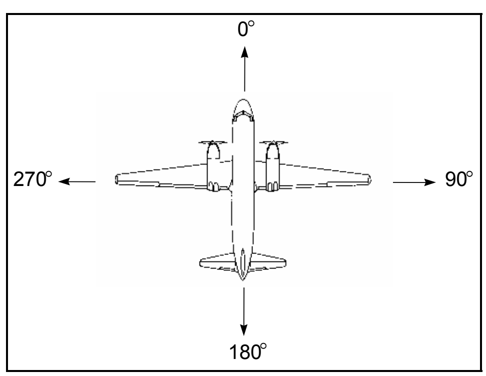

Figure 4-1 Direction of Noise (in degrees)

As explained in Chapter 3, different metrics are needed to capture different aspects of impacts. When annoyance is due to hearing the sound, A-weighting is used, but when annoyance is due to rattling windows and house vibration, C-weighting is used. Also, an additional adjustment to A-weighting is required to deal with the added annoyance of tones, impulsive sounds, or sounds that startle people.

Because there is a large range of frequencies within the acoustic domain, the energy is typically added up within a band of frequencies across the complete acoustic spectrum. For this reason, data on military noise sources are typically presented in one-third octave band sound levels because it provides a more complete description of the sound. A single octave of sound (described in Chapter Two) is divided into three parts to create a one-third-octave band sound level. These levels will be defined for a specific operating condition and a specific distance from the source. Then, depending upon the application, these one-third octave band sound levels will be added up to create the A-weighted or C-weighted levels.

4.1 FIXED WING AIRCRAFT

With the ultimate objective of mitigating aircraft noise, we must understand how a fixed wing aircraft generates noise. General noise characteristics for aircraft depend on the aircraft operation and aircraft are typically operating in one of four modes:

- Ground run-up mode
- Low subsonic speed mode (such as flying around an airport—typically less than 400 knots)
- Transonic speed mode (used when flying training routes—approximately 400 - 650 knots)
- Supersonic mode (greater than mach one)

4.1.1 NOISE FROM JET AIRCRAFT

When the aircraft is operating on the ground, large amounts of acoustic power are generated by the jet engines (approximately 30 kilowatts, as compared to less than a milliwatt by a human voice) so even the noise of a single aircraft can affect a large land area. The noise from propeller aircraft, due to changes in the directivity pattern from the propeller, will affect a smaller land area but its impact is assessed the same. Figure 4-2 shows the equal sound level contours from a typical jet aircraft and a propeller aircraft. The changing shape of the contours shows the noise is at a different level depending upon the angle where the receiver is standing, relative to the front of the aircraft. This changing noise level, which the receiver detects depending on where he/she is standing, is referred to as the directivity angle. Note: Figure 4-2 shows the **relative** shape of the contours, not the **absolute** level; on average, the F-16 makes much more noise than the C-130.

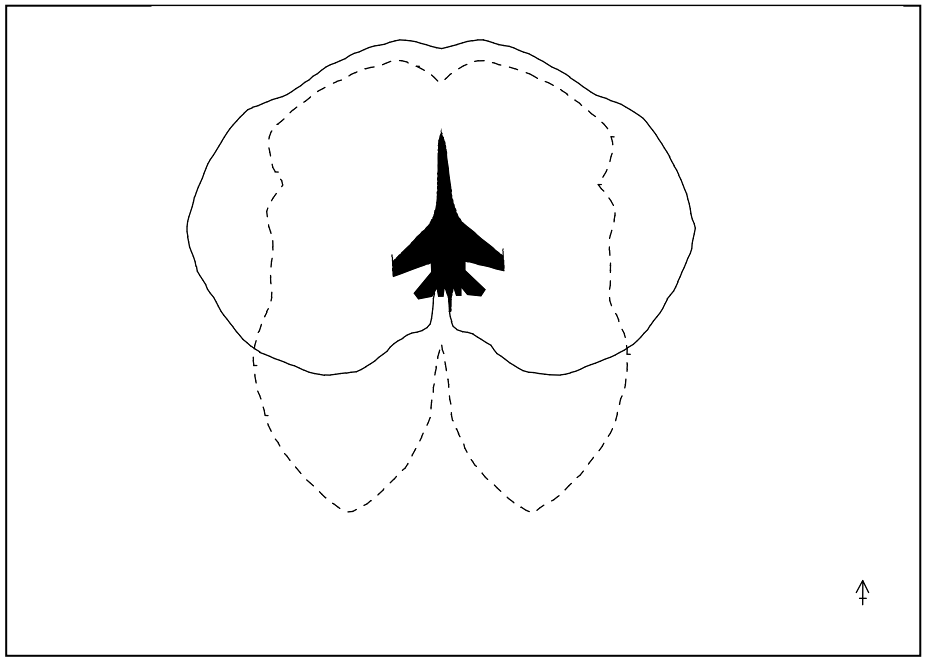

Figure 4-2 Equal Sound Level Contours from a Typical Jet (dashed) Aircraft and a Propeller Aircraft (solid)

Typically, jet aircraft generate noise levels 15 to 30 dB higher than propeller aircraft during takeoff operations. There are two major sources of noise from jet engines: 1) the roar of the jet exhaust resulting from the turbulent mixing of high velocity exhaust gases with the ambient air (see Figure 4-3) and 2) the turbo-machinery and fan noise from rotating blades in the fan, compressor, and turbine stages of the engine. The main noise source is the jet exhaust because only during low thrust is the turbo-machinery noise (i.e., compressor "whine") detectable. On afterburner-equipped aircraft, the increased flow velocity through the afterburner creates significantly more noise than any other power setting.

In the turbofan engine, much of the intake air bypasses the combustion chamber and the primary exhaust. The result is a lower exhaust velocity and reduced jet noise, as shown in Figure 4-4 However, the cost of this particular noise reduction is a noise level composed primarily of a pure tone, in the 2000 to 4000 Hz (cycles/second) frequency range, which is produced by the large fan at the front of the engine. Because of these strong tones, turbofan noise is more annoying subjectively than jet exhaust noise, even at takeoff thrust.

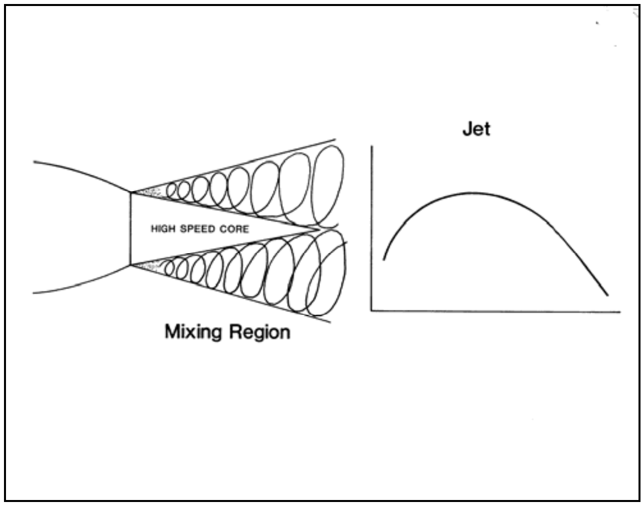

Figure 4-3 Roar of Jet Exhaust Caused by Turbulent Mixing of Gases

The newer high bypass-ratio turbofan engine is designed to minimize fan noise (and increase fuel efficiency). As the name indicates, the ratio of the air that bypasses the combustion chamber is very high. These engines therefore typically have much reduced jet exhaust noise, with fan noise tones occurring at frequencies lower than the 2,000 to 4,000 Hz produced by the turbofan engines previously mentioned. These lower frequency fan tones are less annoying.

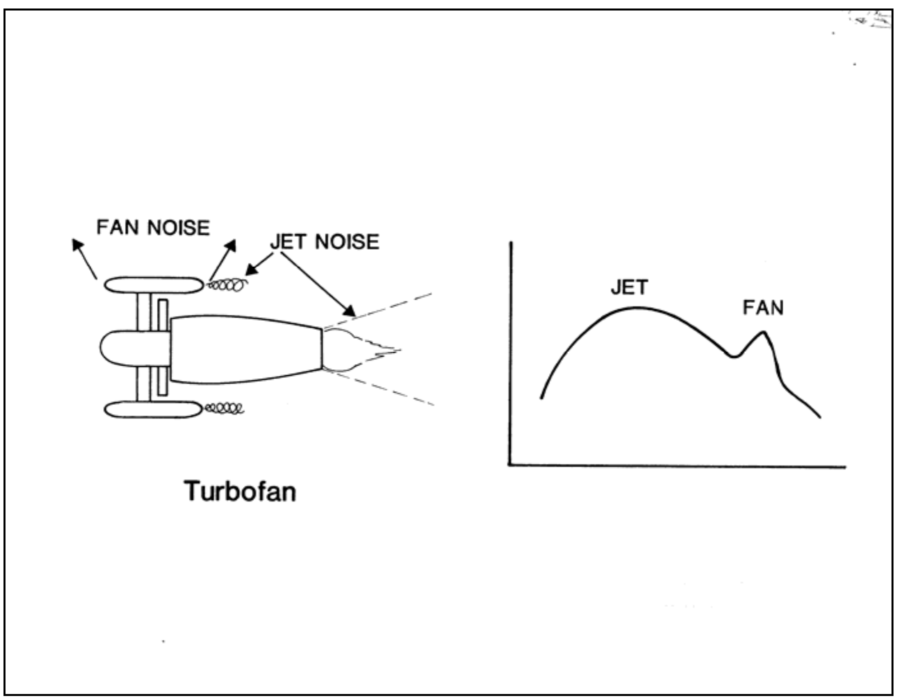

Figure 4-4 Turbofan Engine Noise

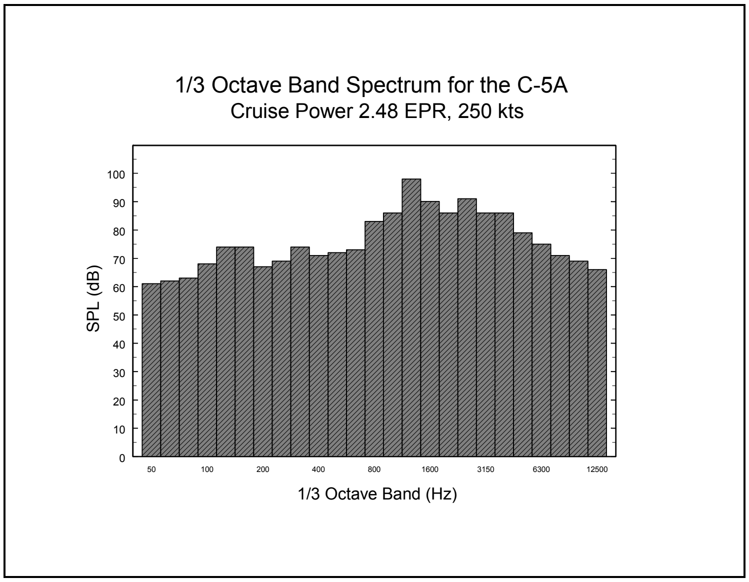

Figure 4-5 Typical Spectra for a Turbofan Aircraft (C-5A)

4.1.2 NOISE FROM PROPELLER AIRCRAFT

Noise from propeller aircraft includes both the vortex and rotational components of propeller noise as well as engine noise (see Figure 4-6). ***Vortex noise*** is generated by the formation and shedding of vortices (whirlpools in air) in the flow past the propeller blades and is a broadband noise source. ***Rotational noise*** (or periodic noise) refers to all discrete frequency noises (tones) that occur at harmonics of the blade passage frequency and is produced by the oscillating pressure field in the air due to the passage of the blade. Because of the relatively lower rotational speed of propellers, most of the acoustic power is found in the lower frequency bands (less than 200 Hz) of the audible spectrum.

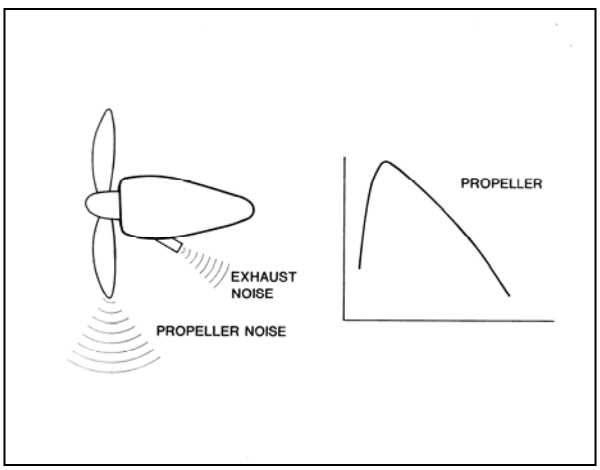

Figure 4-6 Propeller Noise

Whether piston or turbine-powered, engine noise is a secondary source for propeller aircraft. At typical takeoff power, piston-powered aircraft produce greater exhaust noise than turbine-powered propeller aircraft (turboprops) but on approach, turbine-powered aircraft generate audible engine compressor tones.

Figure 4-7 shows a typical spectrum for a propeller aircraft (a C-130) at 90 degrees. Notice the high level, around 63 Hz, which is near the blade passing frequency for this aircraft at this power.

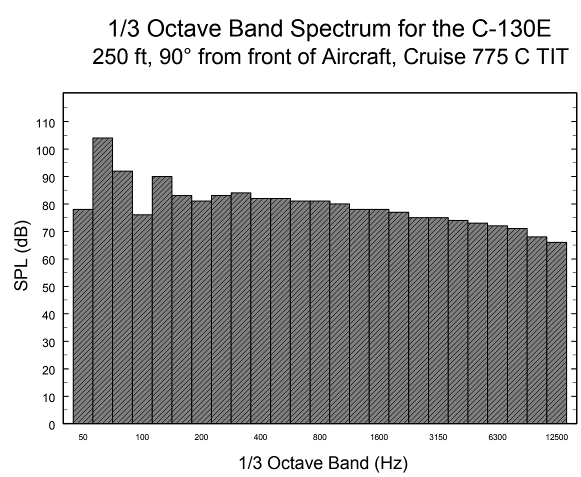

Figure 4-7 Typical Spectra for a Propeller Aircraft (C-130) at 90 Degrees

4.1.3 Environmental Considerations with Ground Run-Up Noise

A ground run-up takes place without the aircraft lifting off the ground. Ground run-up noise is typically a **steady state** type of noise so once set at a particular power setting, the noise is very stable. To assess the impact of this noise, we must examine the particular problem.

Typically, for aircraft run-up noise, the A-weighted metrics are most appropriate since the major concern is people's exposure and subsequent annoyance. For example, if the ground run-up is near an office complex or school, then speech communication inside the building is of primary importance. Therefore, in this case, the assessment could be made using the Preferred Speech Interference (PSIL), a measure for communication impedance discussed in Chapter 3. This assessment would give a good approximation for speech interference or one may choose do a more detailed analysis using the one of the other metrics (Articulation Index (AI), Speech Interference Level (SIL), etc.) also referenced in Chapter 3.

For land use compatibility considerations, the DNL metric should be used. When designing a new building next to a run-up pad, the one-third octave band spectra is required for engineering design. This information is required to select construction requirements for sound transmission loss to achieve a specific indoor noise level. For hearing conservation, the time that the operator is in the sound field and the sound levels at his location are required to calculate noise exposure in L_{eq}.

4.1.4 ENVIRONMENTAL CONSIDERATIONS WITH LOW-SPEED FLIGHT

Around military installations, fixed wing aircraft typically fly from about 160 knots at liftoff to a 350-knot limit imposed by the FAA. With flight, aircraft noise (relative to the receiver on the ground) has changed from the fixed-source, steady-state noise (as in run-up) to a moving source producing a transient noise. Figure 4-8 shows a typical time history of the A-weighted sound level (dBA) that a receiver would experience. The noise source now has the addition of the air flowing past the airframe, called aerodynamic noise, and it contributes to the increased overall noise of the flying aircraft. To assess the impact of this transitory noise, the Sound Exposure Level, or SEL (see Chapter 2), is the best measure of the annoyance response (Harris, 1991).

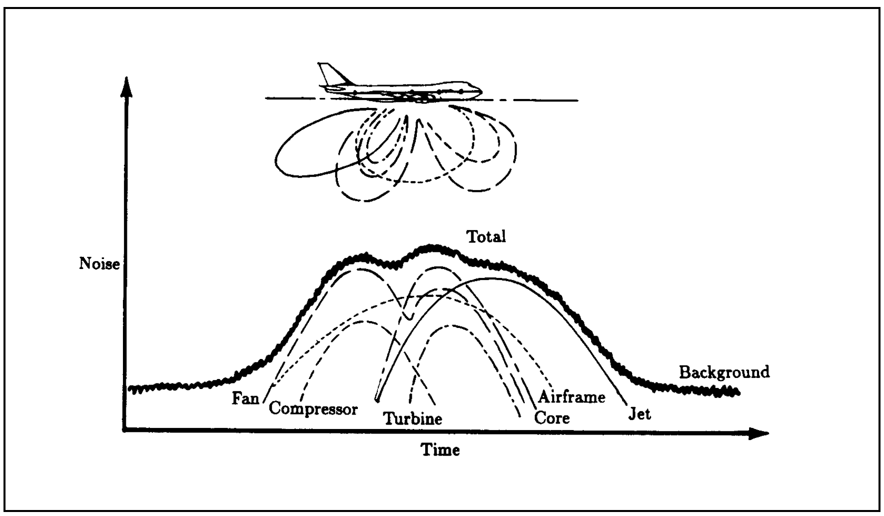

Figure 4-8 Time History of the A-weighted Sound Level (dBA)

Reducing annoyance on the ground, though, is not as easy as simply reducing the SEL. It is true that as the speed of the aircraft increases, the SEL decreases due to the shorter duration of the noise event. However, to increase the speed, more thrust is required which increases the noise level generated by the aircraft; on the ground the noise doesn't last as long but its intensity is much greater. So, in terms of annoying people or animals, flying faster generates greater sound intensity and this, coupled with an increased probability of startle (due to the quicker onset form a fast approaching aircraft), negates any positive effect on annoyance that a lowered SEL may have. Thus when it comes to reducing irritation on the ground, it is generally best to use a conservative thrust setting and avoid sensitive areas as much as possible.

4.1.5 ENVIRONMENTAL CONSIDERATIONS WITH TRANSONIC FLIGHT

As aircraft in flight increases its speed, the aerodynamic noise (noise created when the airframe disturbs the air as it passes through it) begins to dominate over the jet noise and the turbo machinery noise. This aerodynamic noise is analogous to the wake coming off of a boat as it passes through the water.

Along Military Training Routes (MTRs) and Military Operating Areas (MOAs), aircraft can fly at low-altitudes (< 1000 ft.) and at high-speeds, (>350 knots). The noise generated by this type of operation is transient in nature so it can include a rapid onset of the acoustic stimulus. This rapid onset may produce a startle or surprise response in people and animals if the aircraft passes directly over them. The methods for assessing the effects of rapid onset were discussed in Section 2.2.2.4 and 3.1.1.6.1.

4.1.6 ENVIRONMENTAL CONSIDERATIONS WITH SUPERSONIC FLIGHT

Figure 4-9 shows the generation and propagation of a sonic boom. As with a wave from a boat, the sonic boom moves continuously with the aircraft. The term “breaking the sound barrier” is misleading since the aircraft does not go through a physical barrier. As long as the aircraft is flying faster than the speed of sound, a sonic boom is being generated. The boom may or may not propagate to the ground just like the wave from a boat may or may not reach the shore but, for steady conditions, the sonic boom that reaches the ground is called a “carpet boom” (since it covers a large area). It is important to note from this figure that the sonic boom propagates forward of the generation point. Even though in steady state flight the boom intercepts the ground behind the aircraft, that boom was generated at an earlier time in the flight.

When the aircraft’s speed exceeds the speed of sound there are two primary shock waves; one emanates from the front of the aircraft (bow wave) and the other emanates from the rear of the aircraft (tail wave). If the duration between the bow wave and the tail wave is great enough, a receiver on the ground would hear the sonic boom N-wave as two booms– the first boom is the bow passing the receiver and then the second boom is the tail wave. The aircraft's length, altitude, speed, and the weather conditions determine the size and shape of the N-wave.

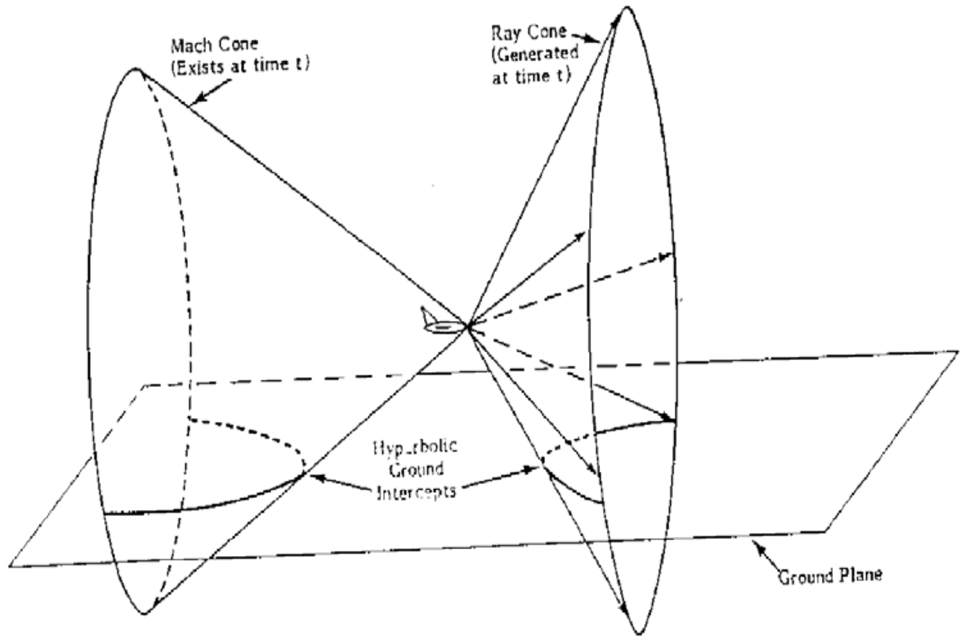

Figure 4-9 Generation and Propagation of a Sonic Boom

The shape of the N-wave is shown in Figure 4-10. This figure shows the bow wave with a compression occurring and a slow expansion below the atmospheric pressure after a sudden decompression at the tail wave. Generally for military aircraft, the bow and tail shock waves are similar strengths.

When an aircraft maneuvers (accelerates, turns, dives, or climbs) in supersonic flight, the sonic boom can be folded on top of itself. This creates an increase in the overpressure at a location that is referred to as a "focus boom." The overpressure can be two to five times the overpressure from steady flight. This focal area is very localized and it impacts a much smaller area than a carpet boom. Figure 4-10 also shows the shape of the focused boom.

4.1.7 REFERENCE NOISE DATA FROM FOUR MODES OF FIXED WING AIRCRAFT OPERATION

Reference noise data on almost all military aircraft operating at various conditions are available as a database used by the NOISEMAP and MR_NMAP programs described in Chapter 5. This database is called NOISEFILE (USAF, 1997a) and includes the aircraft noise levels for subsonic flight, hush house conditions, and data for engines operating in test cells. The measurements in this database have been collected over many years as aircraft have become operational. Thus, some care must be taken in using the database to ensure that the appropriate engine parameters are used in the models.

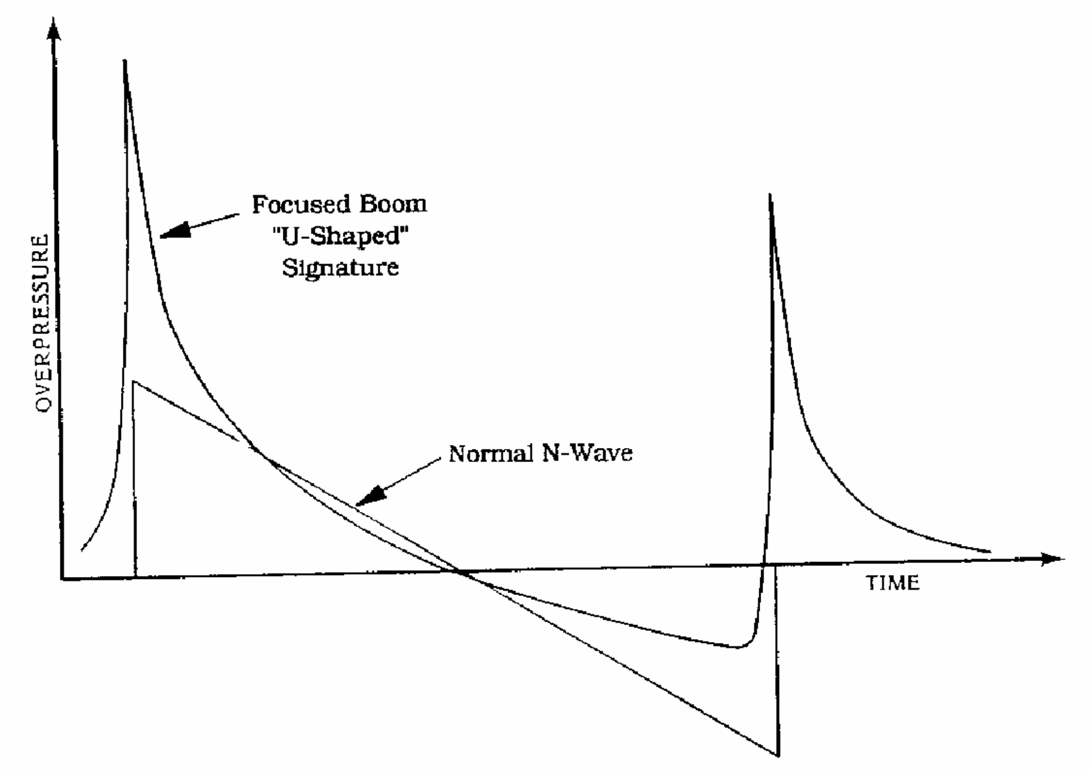

Figure 4-10 Two Forms of Sonic Boom

The USAF has also developed a database of sonic booms from most supersonic aircraft. This database is called BOOMFILE (Lee and Downing, 1991) and includes sonic boom signatures from steady level flights at various altitude and Mach numbers. This database serves to verify sonic boom predictions models for single events such as Carlson's Model and PCBoom3 that are also discussed in Chapter 5.

4.2 ROTARY WING AND VERTICAL TAKEOFF AND LANDING (VTOL) AIRCRAFT

Rotary-wing operations are separated from fixed-wing aircraft because of their complicated noise generating mechanisms.   Rotary-wing operations are similar to fixed-wing operations in having ground run-ups and flights at low subsonic speeds but helicopters and Vertical Takeoff and Landing (VTOL) aircraft have other unique operating characteristics and subsequent mitigation methods.

4.2.1 GROUND RUN-UP AND HOVER

An operation unique to the helicopter is hovering. As a noise source this can be treated just like a fixed wing ground run up operating in a unique condition with the following exception: A helicopter in hover condition is an asymmetrical source. Whereas fixed wing aircraft are typically measured on one side and symmetry is assumed, rotary wing aircraft must be measured completely around the source to acquire the full directivity pattern. For the ground run-up conditions, helicopters operate in typically three distinct conditions:

- Ground Run-Up – the rotors operate without any lift.

- In-Ground Effect (IGE) Hover – the aircraft is physically off the ground but the downwash from the main rotor is reflecting off the ground and providing some lift for the helicopter. This is typically within 1.5 rotor widths of the ground and can be accomplished at a much lower power setting than higher hovers.

- Out of Ground Effect (OGE) Hover – occurs at altitudes above 1.5 rotor widths of the ground and requires more power (i.e., more noise will be produced).

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4.2.2 ACOUSTIC CHARACTERISTICS OF FLIGHT OPERATIONS

Helicopters make more noise when landing then when taking off; the opposite pattern from fixed wing aircraft. Furthermore, helicopter noise levels can be 2 to 10 dB higher than propeller aircraft noise levels during landing operations. All this adds up to a very complex three-dimensional directivity pattern of the total noise from a helicopter. Directivity patterns will differ from one type of helicopter to another and also will differ from one type of operation to another within helicopter type. Military helicopters also operate close to the ground to avoid detection, an operation known as Nap of the Earth (NOE) flying. But unlike jet aircraft, helicopters do not operate at transonic or supersonic speeds. A helicopter flying faster than 200 knots is a rarity.

Helicopter noise is produced by a combination of vortex, rotational, and engine noise sources. Helicopters emit an additional type of rotational noise called "***blade slap***." Blade slap is a high-amplitude periodic noise plus highly modulated vortex noise that is caused by fluctuating forces on the blades from the cutting of one blade's tip vortices by another blade. It is a distinctive, low frequency throbbing sound that increases during descent, maneuvering, and high-speed cruise operations.

Other types of noise more-or-less specific to helicopters are:

- **Blade-Vortex Interaction (BVI) noise** – occurs when a rotor blade cuts through a vortex originating from the same or another blade. BVI is the noise source most commonly associated with helicopter operations near terminal areas.

- **High-Speed Impulsive (HSI) noise** – is related to the transonic flow field around the blade tip.

- **Rotational noise** – has its origins in steady and harmonically varying loads on the rotor blades often resulting in low-frequency noise. Note: low frequency noise propagates much farther than high frequency noise and this is why one can hear a far off approaching helicopter long before it passes overhead.

- **Broadband noise** – is primarily the result of engine exhaust and random loading of the blade.

- **Rotary wing noise** – is highly directional and can vary widely depending on flight mode, airspeed, and rate of climb/descent. During hover and during flight, higher noise levels characterize rotary wing noise forward and on the advancing rotor side compared to behind and to the retreating side.

In addition to the acoustic directivity from the main rotor, there is acoustic directivity from the tail rotor. Figure 4-11 shows the directivity pattern for the first three tail rotor tones of a Bell Griffon 412SP helicopter. This directivity combines with the directivity of the main rotor and the engine noise to give the overall acoustic directivity of each particular model of helicopter.

4.3 UNCONFINED EXPLOSIONS

The military trains with a wide variety of uncontained explosions the largest of which are live bombs dropped into impact areas. At Army installations, the 2,000 lb bomb (dropped by the Air Force or Navy) is generally the most intense explosive source.

However, other common sources of uncontained explosions are high explosive (HE) rounds. Generally, the largest HE rounds are from 155 mm howitzers (approximately 15 lbs of explosive) but 105 mm howitzer rounds and 120 mm, 81 mm, and 60 mm mortar explosives are also in wide use. Additionally, engineers also train with uncontained explosives to learn how to clear minefields or to break through a field of concertina wire.

Finally, ammunition plants and storage depots operate demolition grounds to dispose of excess or obsolete ammunition.

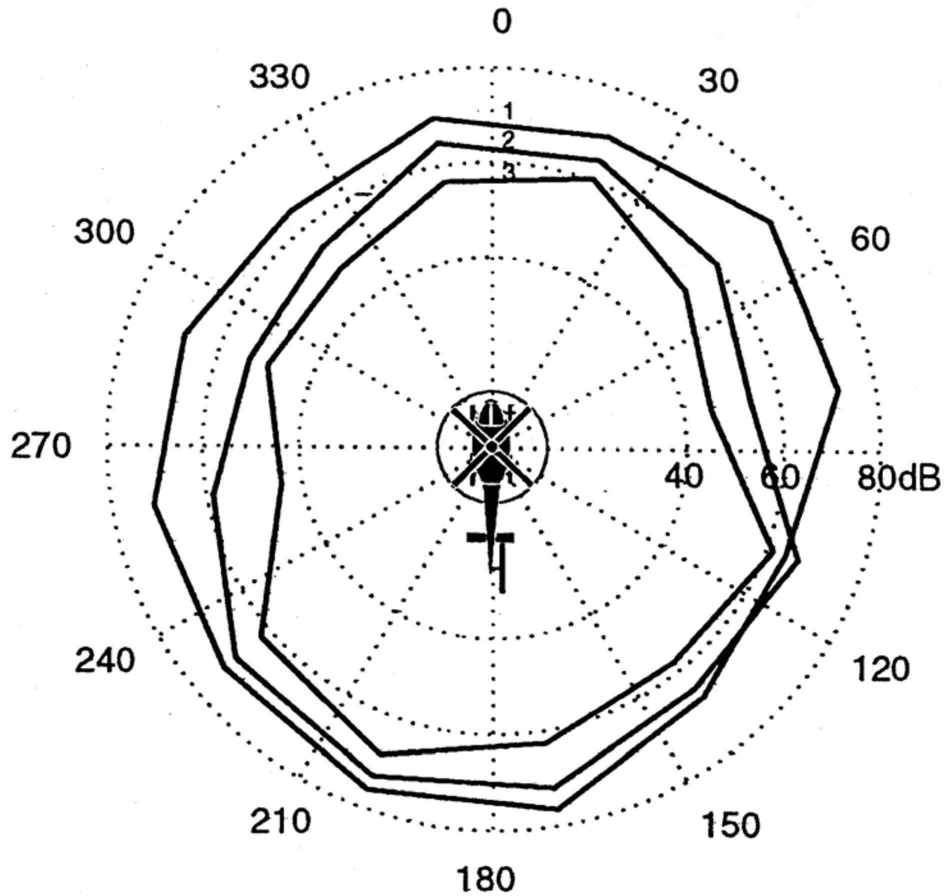

Figure 4-11 Directivity Pattern of the First Three Tail Rotor Tones of a Bell Griffon 412SP (reproduced from Browne and Munt, 1999)

All of these explosions share three common features:

- They can be described in terms of equivalent explosive weight.
- They produce hemispherical sound fields.
- The low frequency components of their acoustic signature can propagate long distances under certain meteorological conditions.

4.3.1 EQUIVALENT EXPLOSIVE WEIGHT

Many military demolitions are combinations of more than one kind of explosive. Knowing the absolute weight of the explosive gives an incomplete picture of the noise level since explosives differ in their efficiency. To predict the noise level from a particular combination of explosives, the environmental noise technician must convert each component to the equivalent weight in TNT (trinitrotoluene). Table 4-1, reproduced from Raspet and Bobak (1988) lists the efficiency factors for correcting different kinds of military explosive to equivalent weight in TNT.

Type of Explosive		***Efficiency***
TNT		1.00
Tetrytol, M1, M2		1.20
Composition C3, M3, M5		1.34
Ammonium nitrate (cratering charge)		0.42
Sheet explosive, M186, M118 (demolition charge)		1.14
Military dynamite M1		0.92
Straight dynamite (commercial)	40%	0.65
	50%	0.79
	60%	0.83
Ammonia dynamite (commercial)	40%	0.41
	50%	0.46
	60%	0.53
Gelatin dynamite	40%	0.42
	50%	0.47
	60%	0.66
PETN		1.66
Tetryl		1.25
Composition B		1.35
Amatol 80/20		1.17
Black powder		0.55
Nitrostarch		0.80
Pentolite		1.27

Table 4-1 Efficiency Factors for Calculating Equivalent Weights

4.3.2 HEMISPHERICAL SOUND FIELD

Unlike the various weapons discussed later in this chapter, explosions generate the same sound in all directions. As long as the explosive is buried or detonated at the surface, the sound field will be hemispherical. Exceptions to this general rule include a steel cutting charge used to destroy a bridge or a high-burst registration from artillery. In those cases, the sound field is spherical.

A note on high-burst registrations: In some combat scenarios, the high explosive round explodes above the target area, scattering shrapnel. When this happens, the sound carries farther and is louder outside the installation boundary. A high-burst registration can be particularly annoying at night because the explosive noise can propagate a long distance through nighttime temperature inversions.

4.3.3 LOW FREQUENCY COMPONENTS

The spectra of military explosives usually contain more low frequency sound than from the confined explosions of guns. A typical spectrum from a 5 lb. charge of plastic explosive (C4) is shown in Figure 4-12. Note that the spectrum has the most energy at 31 Hz. This is significant because there are three important characteristics about signals at 31 Hz:

- They are so low that humans do not perceive that the sound level is relatively high.
- Wood frame residential construction and double-hung windows respond with rattles and vibration.
- The signals propagate over much longer distances than signals of higher frequency.

The spectrum of uncontained explosions is related to the size of the explosion in that the larger the explosion, the lower the spectrum. Thus, charges smaller than 5 lbs. have a spectrum peaking at a frequency higher than 31 Hz, and charges larger than 5 lbs. have a spectrum peaking at a frequency lower than 31 Hz.

When explosions have a spectral energy below 20 Hz (like those near demolition grounds, bombing ranges, or artillery impact areas) people barely notice an explosion when outdoors but, because of induced vibrations, become intensely annoyed when they step inside their homes. An Army analysis of noise complaints from the 1970's showed that people complaining about explosions are more likely to be concerned about effects on their homes than those complaining about aircraft noise.

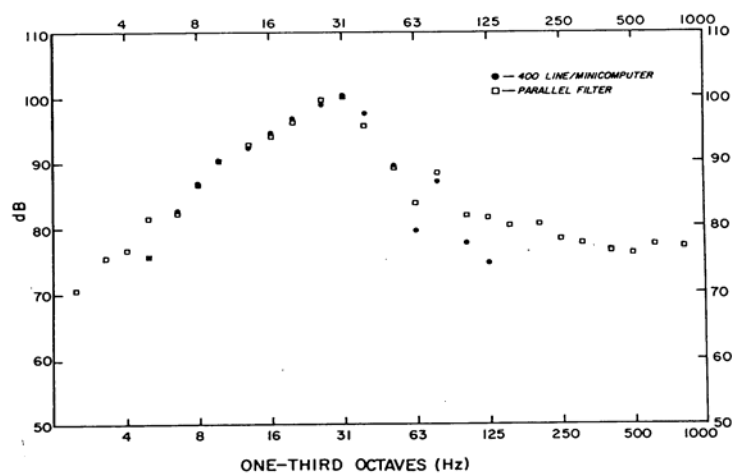

Figure 4-12 One-Third Octave Spectra of 5-Pound Charges of C-4

4.4 SHAPED EXPLOSIONS

Shaped explosives are used by combat engineers and are designed to direct explosive energy in a particular direction. For instance, a 15 lb. shaped charge may be configured to direct its explosive energy into the ground to make tank traps. Since the energy is directed to the ground, that charge makes less noise than a 15 lb unconfined explosion (which would make sound that can travel in all directions). Similarly, the Mine Clearing Linear Charge (MICLIC) consists of a 160-meter length of explosive cord fired over a minefield. When the MICLIC is detonated, the explosive energy generates a pressure wave to the side that detonates pressure-actuated mines.

4.5 EXPLOSIONS CONFINED TO GUN TUBES

When an explosive is confined inside a gun tube or rocket casing, the acoustics become more complicated. The smaller the caliber of the gun tube, the higher the dominant frequencies in the acoustic signature; the longer the gun tube, the lower the amount of acoustic energy released into the air. The acoustic signature is also shaped by other factors such as silencers and muzzle brakes.

4.5.1 ACOUSTICS OF PROPELLANT BLASTS

The most common explosive sources at DOD installations are propellant blasts from gun tubes, and the most common type of gun tube is the unmuzzled variety. Unmuzzled gun tubes range in size from the M-9 military side arm all the way up to 16-inch naval guns.

When a bullet or projectile is fired, an unmuzzled gun tube generates 12 to 14 dB more noise at zero (0) degrees azimuth (directly in front of the gun) than at 180 degrees azimuth (directly behind). At 90 degrees to the direction of fire, the level is 6 to 7 dB greater than at the same distance directly behind the firing point. Pater (1981) demonstrated that the change in level with direction of fire could be modeled by using the cosine of the angle between the direction of fire and the direction of the listener.

Pater also showed that the sound level of a propellant blast behind a firing point depends on the elevation angle of the gun tube. A direct fire weapon, such as the 120 mm tank cannon, is nearly horizontal when it fires and the sound level experienced by someone standing on the ground is 12 to 14 dB higher in front than in back. However, indirect fire weapons, such as a mortar, are fired at an angle so as the angle of elevation increases so does the noise level behind the firing point.

But the position of the gun tube is not the only factor influencing its acoustic signature. The design of the tube itself influences highly the sound type and level produce by a gun. Some variables in gun tube design that that influence the sound it makes are:

Muzzle Brakes

The presence or absence of a muzzle brake has a strong affect on a weapon's acoustic signature. Muzzle brakes are employed to deflect some of the propellant blast to the rear and sides in order to reduce the weapon's recoil. Gun tubes mounted on heavy platforms do not require muzzle brakes nor do tank cannons, naval gun ships, or the Mark 75 and 45. But weapons such as the towed 155 mm howitzer used by Marine and Army field artillery (the M-198) are equipped with a muzzle brakes to compensate for their relatively light weight. The contrasting acoustic directivity between 155 mm howitzers with and without a muzzle brake is shown in Figure 4-13 (reproduced from Schomer *et al*., 1979). Notice that the sound field from the howitzer with the muzzle brake is more circular.

Barrel Length

In simple terms, and with all other things being equal, shorter guns are louder than longer guns. When a projectile is fired from a longer gun tube, it leaves the tube at a higher velocity than when fired from a shorter tube. This is because the longer tube allows more of the energy from the propellant to be converted into the projectile's kinetic energy before the projectile leaves the tube (and the remaining propellant washes out of the end of the barrel). Since this remaining propellant is responsible for much of the noise that a gun makes, it stands to reason that the more propellant energy that goes into moving the projectile, the less will be left to make noise. In terms of battlefield application, mortars have relatively short gun tubes and howitzers have relatively long gun tubes. So, if the same weight of propellant is used in a 107 mm mortar and a 105 mm howitzer, the propellant blast (and thus the sound) from the mortar will be higher than from the howitzer.

Overall Barrel Size (Diameter/Length/Charge)

A third design variable that determines a weapon's acoustic signature is the overall size of the gun tube. Obviously, gun tubes that are large in both length and diameter are expected to fire a commensurately large projectile and propellant charge.

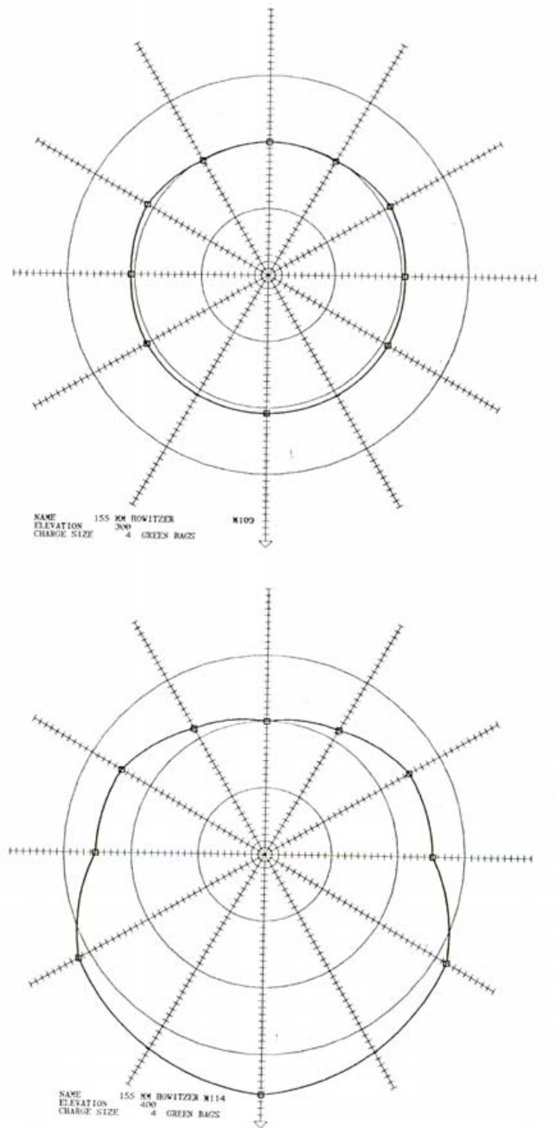

Figure 4-13 Comparison of a 155 mm Howitzer with Muzzle Brake (upper contour) with 155 mm Howitzer without Muzzle Brake (lower contour)

Acoustically, as the gun tubes increase in size, the deepness of the sound of the propellant blast also increases. For example, the spectrum of a 5.56 mm rifle has most of the energy around 500 Hz. while the spectrum of a 120 mm tank cannon has most of its energy around 15 Hz. Because the human ear is much less sensitive to sound at 15 Hz than at 500 Hz, a rifle at a peak level of 115 dB would sound a lot louder than tank cannon at a peak level of 115 dB. Note: This fundamental difference is why sounds of rifles are measured with A-weighting and of tank cannon with C-weighting (as discussed in Chapter 2).

4.5.2 ACOUSTICS OF BULLETS AND PROJECTILES

Some rounds fired from long gun tubes (including rounds from military rifles, the IFV, tank cannon, and howitzers fired with large charges) are supersonic. As with a sonic boom, these supersonic speeds result in bow shock waves (also known as a ballistic wave). The bow shock wave propagates out from the path of the bullet as shown for the 120 mm gun in Figure 4-14.

The sonic boom from a projectile differs from the aircraft sonic boom discussed in Section 4.1.6 in three ways:

- The sonic boom from the projectile is less intense and at a higher frequency than the boom from an airplane, because the projectile has a shorter length and diameter than an airplane.

- The sonic boom from the projectile does not have a separate bow wave and tail wave.

- The projectile travels in a straight path, so there is not a focused boom as shown for jet aircraft booms in Figure 4-10.

Rounds leave the 120 mm gun at speeds over 4 times the speed of sound (referred to as Mach 4). However, while speed is one of the important variables in determining the size of the shock wave, an even more important variable is the diameter of the round itself. This importance of diameter can be illustrated by the difference in shock waves from the 120 mm HEAT-TPT and SABOT rounds.

HEAT is an acronym that stands for High Explosive Anti-Tank, and TPT is an abbreviation for Target Practice with Tracer. As stated above, the HEAT round is 120 mm in diameter and has a fuse protruding from the front. When the fuse strikes armor, a shaped charge explodes forward into vulnerable areas of the opposing tank. During training, crews avoid damaging targets by using inert training rounds (HEAT-TPT) that have a tracer allowing these rounds to be seen at night.

Unlike the HEAT round, the SABOT or Armor Piercing Discarding Sabot (APDS) drops its sides after leaving the gun tube. When the sides fall away, the projectile’s kinetic energy is transferred from the beginning 120 mm projectile to a 40 mm tungsten (or, in combat, depleted uranium) core. Because the remaining projectile is now smaller and faster, it can more easily pierce armor and, at the same time, the new smaller diameter produces a smaller ballistic wave than the HEAT round (Schomer and Raspet, 1984).

As an aside, people living forward of tank gunnery ranges will often hear the muzzle blast and ballistic wave as two distinct sounds. Since the tank round travels at speeds greater than Mach 4, the ballistic wave will be heard first and the muzzle blast follows shortly afterward.

Figure 4-14 shows the ballistic wave and muzzle blast noise pattern of a HEAT round targeted at 4 km. In Region I, no ballistic wave exists, and Region II shows where the ballistic wave is diffracted and decays faster than the propellant blast wave. The hatched regions, labeled III and IV, are where the ballistic wave is significant. In Region III, the muzzle blast is greater than the ballistic wave, and in Region IV, the ballistic wave is louder than the muzzle blast. (The dashed line shows the zone IV cut off if the target range were 3 km rather than 4 km.)

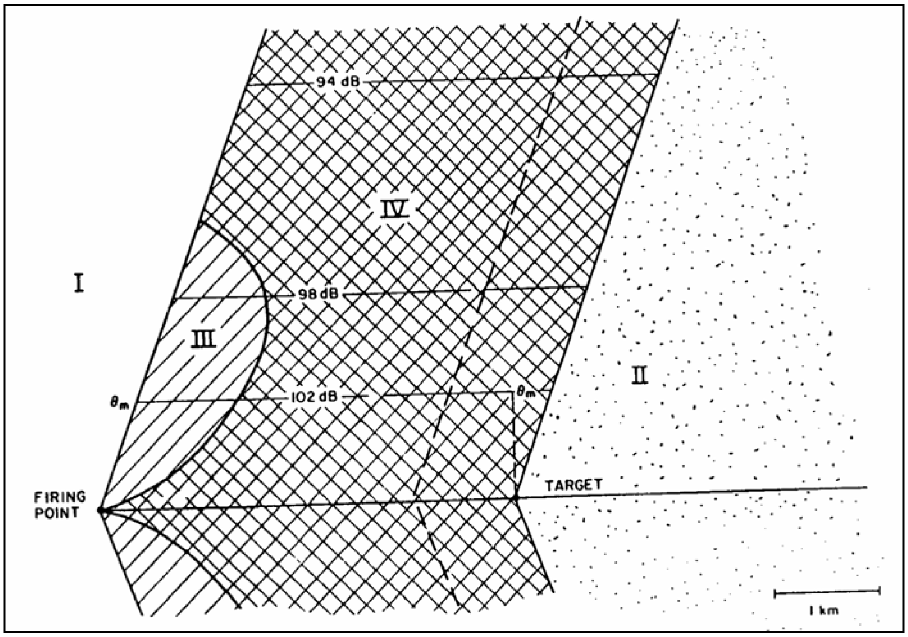

Figure 4-14 Noise Pattern from Muzzle Blast and Ballistic Wave of HEAT Round

4.6 ROCKETS AND MISSILES

Rockets and missiles have two noise impact areas, the firing point and the impact point. Both are much like the noise from explosions but the firing point has a distinct directivity pattern associated with it. While rockets and missiles may come in many varieties, a common feature of all of them is that the propellant noise is highest to the rear.

Combat forces generally use rockets in the following configurations:

- Direct fire at ground targets from a ground position

- Indirect fire at ground targets from a ground position
- Direct fire at an aircraft from a ground position (anti-aircraft)
- Direct fire at a ground target from an aircraft
- Direct fire at an aircraft from an aircraft

Each of these situations presents a unique acoustical environment. For instance, the acoustic signature of shoulder-fired rockets is relatively short and more of a “bang” relative to the signature of larger rocket motors that extend over many seconds. For all types, measurements are made with the C-weighting because of the sizable amount of low frequency energy. The two tracings in Figure 4-15 illustrate the importance of the low frequency energy in the signature of the Hera medium-range ballistic missile.

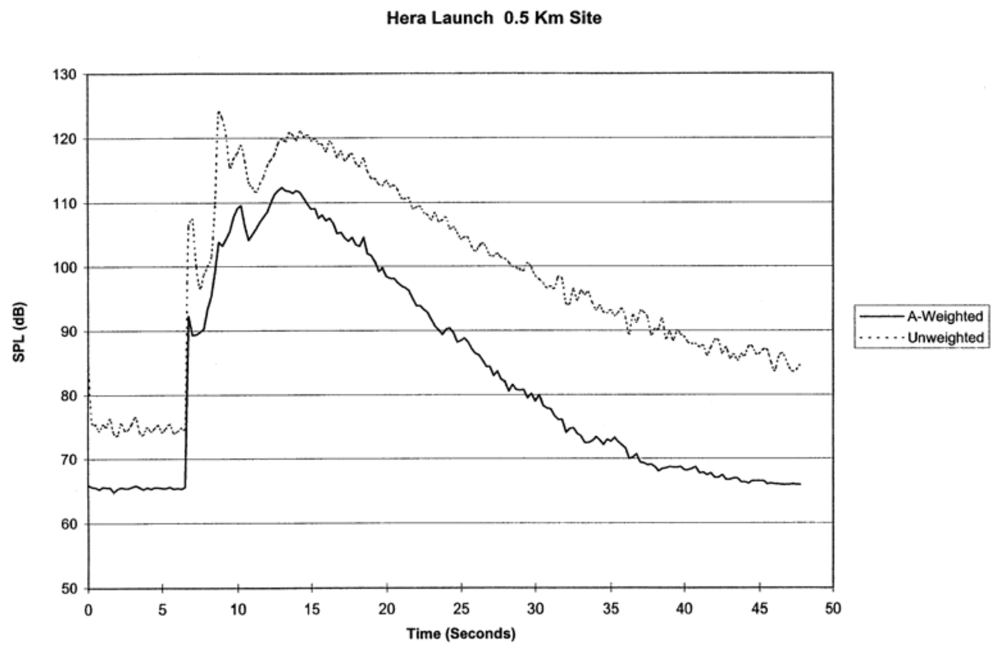

Figure 4-15 Acoustic Signature of the Hera Medium-Range Ballistic Missile

4.6.1 DIRECT FIRE AT GROUND TARGETS FROM A GROUND POSITION

Ground forces employ several rockets against armored targets, such as tanks and infantry fighting vehicles. The smallest of these is the Light Assault Weapon (LAW), which is fired by a standing soldier who has the rocket tube resting on his shoulder. More effective against armor are the Dragon antitank rocket and the AT4. But the most effective against armored targets is the TOW (Target Optical Wire-Guided). This weapon is carried on a HUMVEE or some other small tactical vehicle and, because of their short range; these weapons can be fired safely at small installations. Nevertheless, the Army has had to relocate several ranges for these weapons because of noise complaints; having homes less than 1 kilometer behind the firing points is undesirable.

4.6.2 INDIRECT FIRE AT SURFACE TARGETS FROM A SURFACE POSITION

For attacking distance targets, U.S. forces use weapon systems that are propelled by rockets. For example, the Multi-Launch Rocket System (MLRS) can fire one or more rockets against distant armored targets. Because of the long range of the MLRS, the actual rounds can only be fired at large installations, such as White Sands Missile Range. In order to train at smaller installations, the Army developed a special short-range training round. Both the real and training rounds leave the rocket tube at supersonic speeds. For this reason, the ballistic wave must be taken into consideration when assessing the MLRS. Missiles are also employed on surface ships and varying from the small Standard missile to the Tomahawk cruise missile to the Trident II D-5 ballistic missile. The noise from these missiles is contained near the firing point, except for ones that obtain supersonic speeds where the ballistic wave must be considered. For over water supersonic flight, sonic boom penetration may be an issue in regards to potential effects on marine mammals.

4.6.3 DIRECT FIRE AT AN AIRCRAFT FROM A SURFACE POSITION (ANTI-AIRCRAFT)

The primary antiaircraft weapons for ground forces are:

- Shoulder-fired Stinger missile,
- Vehicle-mounted Stinger system (Avenger)
- Vehicle-mounted Chaparral
- Patriot system
- Hawk
- Sea Sparrow, Rolling Airframe, and Standard missiles (for naval forces)

These weapons are fired so far away from the installation boundary or land as not to be a noticeable noise source.

4.6.4 DIRECT FIRE AT A GROUND TARGET FROM AN AIRCRAFT

Aircraft can attack with an array of missiles at ground and surface targets. These missiles range in size from 2.75-inch rockets fired by helicopters to the Maverick and SLAM-ER cruise missiles launched by tactical jets. The noise from these missiles is associated with three phases: Launch, flight, and explosion. The launch and flight noise are normally not an issue since they occur within the boundary of firing ranges but the explosion noise is similar in detail to the open-air explosions discussed in section 4.3.

4.6.5 DIRECT FIRE AT AN AIRCRAFT FROM AN AIRCRAFT

Missiles are also used in air-to-air combat and major types include the Sparrow, Sidewinder, Phoenix, and AMRAAM. The noise from these missiles is normally minimal since they are used within ranges and are launched at high altitudes, which provides a significant buffer to people and wildlife.

4.7 LAUNCH VEHICLES

In response to the planned introduction of a new launch vehicle into the United States spacecraft fleet in the 1990's, a study of rocket noise prediction techniques was initiated. The new vehicle, or family of vehicles, will be part of the Advanced Launch System (ALS) program. Existing prediction methods are empirical, primarily based on data obtained from controlled experiments performed during the late 1950's and the 1960's.

Ground acoustic data measured during launch is typically classified as near-field (on or near the launch pad) or far-field. Following ignition, the engine exhaust is deflected out from under the pad and into a trench (or flame bucket). Typically, the exhaust trench is partially covered and acoustic levels on the vehicle peak as the plume begins to impinge on the pad a few seconds after ignition. Near-field acoustic levels (including those on the vehicle) may be affected by the proximity of the exhaust exit plane to the bottom of the bucket, the presence of nearby structures, and whether or not the trench is covered or uncovered (Eldred, 1959 and Potter & Crocker, 1966).

Launch vehicles also have a strong low frequency component that can affect buildings in the nearby vicinity. Moreover, as the rockets proceed into orbit, they reach supersonic speeds quickly and generate sonic booms that intercept the ground far down track from the launch point. The curved path to orbit can also create a focused sonic boom that can increase the overpressure in a limited area by a factor of three to five from that of a normal boom.

4.8 SURFACE SHIPS

For communities, noise from surface ships is generally not an issue primarily because they operate in open waters. Even when surface ships are operating near land, they are usually in the industrial setting of docks so environmental noise characteristic data is mostly non-existent for surface ships.

An exception is landing craft, which operate ship-to-shore. Of the two types of landing craft, the air-cushioned craft generates the most noise because of its two shrouded airscrews and four lift fans. These fans are powered by 4 gas turbine engines and generate noise levels similar to propeller aircraft. When these ships operate near the shoreline, their noise may reach communities along the shore. While noise data for the U.S. Navy Air Cushion Landing Craft (LCAC) are available (Burke, 1980), the DOD does not have an adequate noise model with which to use these noise data. In this case, modeling is complicated by the need to simulate the propagation of sound through the water-to-land interface. As a result, when a controversy arose over the stationing of the Army's Light Air Cushioned Vehicles (LACV) at Fort Story, Virginia in 1983, the assessment could only be carried out through on-site measurements.

4.9 MOTOR AND TRACKED VEHICLES

There are two reasons for DOD installations to be concerned with motor and tracked vehicles. First, military family housing may be adversely impacted by civilian motor traffic (such is the case at Fort Hamilton in Brooklyn, New York where some units are exposed to traffic noise at an L_{dn} in excess of 75 dBA). The other reason is that communities near military training areas may be annoyed by military trucks and tracked vehicles. In other words, given the right conditions, civilian traffic can be just as annoying to the military as military traffic can be to civilians.

On a well-traveled highway, motor vehicles can be described as an acoustic line source. While the noise from an individual vehicle is transient in nature, the heavy use on most roadways makes the road a fairly continuous noise source. Noise models like the Transportation Noise Model (TNM) are available for use in describing these types of noise impact areas.

4.9.1 TYPES OF MOTOR AND TRACKED VEHICLE NOISE

Road Vehicles

The noise emitted by an automobile is due primarily to tire noise generated at the tire/road surface interaction. The noise output of trucks, however, is a more complicated phenomenon. In general, traffic consists of a mixture of vehicles, randomly located relative to one another, traveling at a variety of speeds. The noise exposure of a roadway can be determined from the volume flow (in vehicles per hour) and the average speed (in miles per hour) for each class of vehicle on the roadway. Trucks should be considered in three distinct classes according to their noise emission characteristics: light, medium, and heavy trucks. Light trucks are two-axle, four-wheeled vehicles such as panel and pickup trucks and their noise characteristics are similar to those of automobiles. Medium trucks are typically gasoline-powered two-axle, six-wheeled vehicles (such as city trucks) without a vertical exhaust muffler. The noise-generation characteristics of these vehicles are also similar to those of automobiles but medium trucks are usually 10 dB noisier than automobiles at the same flow and speed. Heavy trucks are a more complex noise source. These diesel-powered vehicles have three major noise mechanisms located at different heights above ground level tire noise, exhaust noise, and engine noise. Note: For heavy trucks, the combined noise source is assumed to be at a nominal height of eight feet above the ground rather than at ground level (as is the case for automobiles and light /medium trucks).

Off-Road Vehicle Noise Sources

The off-road vehicle noise sources covered in this manual are that of the two types of heavy combat vehicles:

Military Transport Vehicles - Large troop and/or cargo transport vehicles, either wheeled or a combination of wheeled and tracked, operated either on paved or dirt roads. These vehicles are also used to transport military weapons vehicles to off-road training areas.

Military Weapons Vehicles - Usually tracked mobile or self-propelled weapons vehicles (such as tanks, self-propelled howitzers, etc.) and normally operated off-road or on dirt roads.

Military transport and military weapons vehicles operate at speeds well below that of street traffic. The main use of transport vehicles is to move troops and weapons and measurements have shown that transport and weapons vehicles are up to 10 dB noisier than heavy trucks. The major noise sources of these vehicles are the engine, drive gears, and tracks with track noise typically dominating.

Typical of Tracked Ground Vehicles (TGVs) are the Infantry Fighting Vehicles (IFVs) and the main battle tanks and both systems make a similar sound as they travel. Thus it follows that the spectra for a moving tank and a moving IFV are similar as well. For both, the spectrum peaks around the 100 - 125 Hz bands and an example of the IFV spectrum, reproduced from Schomer and Goebel (1985), is provided in Figure 4-16. The low frequencies are from the track interacting with the road and higher frequencies are from the engine.

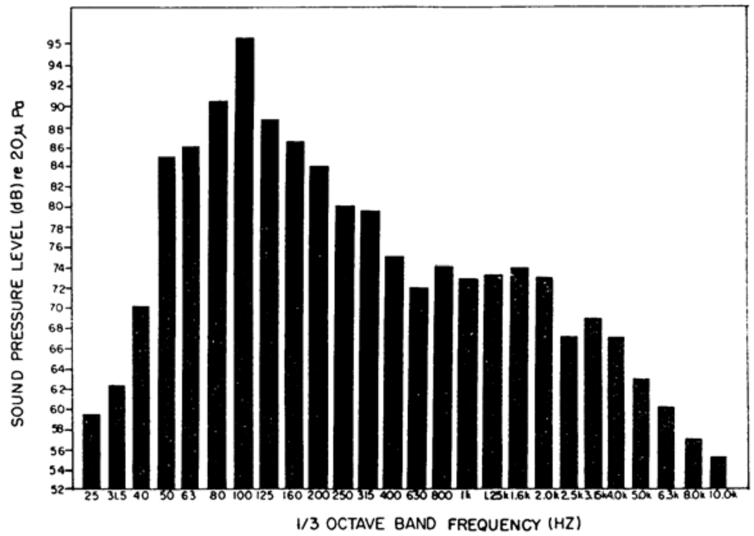

Figure 4-16 Maximum 1/3 Octave Band Spectrum of the M3 Combat Fighting Vehicle During a Drive-By at 100 Ft.

4.10 RAILROAD NOISE

Of the sources discussed in this chapter, railroad noise is the least likely to be a problem for DOD installations. Railroad noise from DOD operations occurs in the vicinity of installation railheads, warehousing operations of the Defense Logistics Agency, and out-ports of the Military Traffic Management Command (e.g., Gulf Outport, New Orleans, Louisiana). Railroad noise is similar to road noise but with higher engine noise and there are two distinct types: noise from line operations (which involves a train moving from one point to another) and noise from yard and siding operations (which also includes car loading and unloading, switching, storage, and maintenance).

<u>Line Operations</u>

Railroad line noise has both engine and car components. Engine noise includes exhaust, casing, intake, and fan noise. Both engine casing and fan noise levels are typically lower than exhaust levels, and intake noise (which is muffled by an air filter) usually cannot be individually identified. The exhaust and casing noise increases with increased horsepower and non-turbocharged engines are about 6 dB quieter than turbocharged engines. Also, an additional significant noise source near grade crossings is the train horn.

A throttle controls the power of a train with eight equal incremental settings. On line runs, the engine is at the eighth setting (full throttle) about fifty percent of the time. The noise level difference between idle and full throttle is about 15 dB. It should be remembered that engine noise is not a function of speed.

Conversely, speed had a great effect on railroad car noise. Railroad car noise is created by the interaction between the steel wheels and the rails and increases with the third power of speed. In addition to the normal interaction noise, there is also wheel squeal, a high-pitched pure tone that occurs when a train traverses a tight curve. Furthermore one must also consider impact noise which is produced when wheels pass over a joint, frog, or signal junction.

In short, the noise exposure from railroad line operations is dependent primarily upon the train speed and length because it is these factors that ultimately determine the noise level and duration.

Yard Operations

Retarders are significant noise sources in a typical railroad yard. Retarders are mechanical devices used to control the velocity of individual cars as a train is being assembled whereby a speed-retarding beam is clamped against the wheels of a car to control its velocity. The resultant noise normally peaks at a frequency of 2000 to 4000 Hz but specific noise levels are dependent on the retarder location and frequency of use.

Another noise source in railroad yards and sidings is car impacts. When a car is being coupled to a string of cars or when a locomotive with a number of cars begins to move, several impacts may occur. These impacts add little to DNL because: (a) the signal is of very short generation, (b) the signal has low amplitude, and (c) the number of impacts typically is not significant.

In general, railroad yard and siding noise levels are highly dependent upon numbers of and types of operations. It stands to reason that the more cars there are being moved around, the higher the noise exposure but most yard-type activities involve loading and unloading rather than switching, coupling, and decoupling of cars. So the important noise sources then become low-speed movement and idling and, although maximum noise levels with these operating modes may not be as high, the duration of these operations will significantly affect the overall noise exposure.

4.11 MISCELLANEOUS SOURCES

Noise complaint files document a number of miscellaneous sources, which have generated complaints through the years. Examples include:

- 24 hour testing of generators along the shore at Fort Belvoir, opposite a quiet neighborhood.

- Low frequency sound from helicopter engine test cells at Stratford Army Engine Plant propagating to homes on the other side of an inlet.

- Cooling tower fans at the Defense Mapping Agency and Walter Reed Army Institute of Research.

- Aircraft jet engine test stand propagating over water from the Naval Air Station Patuxent to a university marine research center.

- Unmanned Aerial Vehicles (UAV) flying over homes outside of Fort Huachuca.

- Low frequency noise from a “hush house” at Langley Air Force Base. Note: A “hush house” is designed to contain the noise from an aircraft engine during testing and repair but the attenuation is most effective for the higher, audible frequencies; the less-attenuated low frequencies can still escape and be a disturbance.

Such miscellaneous sources must be addressed on a case-by-case basis since no noise models are available.

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CHAPTER FIVE

NOISE MODELING

5.1 INTRODUCTION

Taking exact noise measurements at every point on an installation is, for obvious reasons, rarely feasible. The costs in labor and equipment not withstanding, the logistics behind gathering and synchronizing the equipment and personnel needed for stringent data collection every time a particular base has a change in operations are often insurmountable. So, to predict the effects of noise at an installation from a current or proposed condition in a cost effective and reasonably accurate manner, operational/environmental noise scientists employ a tool known as computer noise modeling.

5.1.1 SIMPLE NOISE MODELS

The term “model” is used to describe a formal procedure for predicting sound levels. In simplest terms, a model has three parts:

- A noise database consisting of sound pressure or sound power levels at specific distances from the source

- A set of mathematical assumptions, including meteorological conditions, about how sound propagates from the source to the receiver

- The acoustic measure (dBA, dBC, etc.) of interest

One of the simplest models is bases on the “rule of thumb” that the sound from a *point source* (i.e., the noise is coming from only one point that is not moving) decreases by 6 dB for every doubling of distance from the source. For example, if a measurement at 50 feet from a generator is 86 dB, then it is expected that the sound level would be 80 dB at 100 feet and 74 dB at 200 feet. In this idealized case, the intensity of sound from the point source falls off as the inverse square of the distance. This is known as the inverse square law. The energy radiated from the point source is evenly distributed over the surface of an expanding sphere and the surface area of the sphere is inversely proportional to the distance (radius of the sphere) squared.

A second simple model is the *infinite line source*. The sound pressure level (SPL) from an infinitely long line source falls off at a rate of 3 dB per doubling of distance. This is because the energy distribution is now over the surface of a cylinder, rather than a sphere as in the case of the point source. Because the surface area of the expanding cylinder is inversely proportional to distance, NOT distance squared, it follows that the energy density falls simply with distance from the source, rather than distance squared. Some busy California freeways can be characterized as infinite line sources. Shorter stretches of highway may show attenuation more like 4 dB per doubling of distance from the road.

5.1.2 ADVANTAGES OF NOISE MODELS

As alluded to above, noise models in general use today in the United States more accurately predict the long-term noise environ in the vicinity of airports and military operating areas than can be measured within a reasonable cost. Although many people distrust computer modeling and believe that the only viable way to get an accurate description of a given long-term noise environ is to physically measure it, noise measurement and monitoring are generally very costly and technically difficult to execute correctly; this fact is especially true of measuring complex noise environs resulting from military operations. The fact is most spot-check noise monitoring to verify predicted DNL levels are done by inadequately trained personnel using poor quality or uncalibrated instruments over too short of a period of time. These inadequacies usually lead to dubious comparisons to predicted noise levels because of the long-term effects of variations in aircraft types, operations, weather, etc. However, it should be noted that, as with any computer model, care must be taken to model accurately the true noise environment. Like all computer processing, the output can only be as accurate as the input data. The axiom of “garbage in equals garbage out” (GIGO) is especially true for noise modeling.

Current noise models used by the DOD to assess noise exposure from operations are based on scientific principles and measured noise data. The underlying algorithms, which predict the noise propagation, are based on proven theory and empirically derived relationships. As enhancements are made in computational power, more variables can be included in the modeling of the noise exposure.

The true power of noise models is the flexibility they give an analyst to assess various scenarios. With a model, one can compare the advantages and disadvantages of a defined set of operations, along with a nearly infinite number of alternatives; to determine what scenario best minimizes the noise impacts to the environment while still meeting the training goals. On the other hand, if physical measurements were required to assess the different scenarios, the cost would be too restrictive to explore more than a few alternatives so the best solution may be overlooked and the time frame to complete the assessment would be significantly longer.

Overall, the research and development that goes into these noise models strives to strike a balance between all of the primary variables that influence/control the noise exposure, and making a model easy to understand and operate. For example, acousticians know that atmospheric turbulence greatly influences the received noise levels at any given time. However, the influence of turbulence is minimal when considering long-term noise exposures. Thus, atmospheric turbulence is not included in noise models since the input data and computational requirements are significant with minimal improvement to the predicted noise exposure.

5.1.3 TYPES OF MODELS

There are four basic types of operational/environmental noise models:

- Long-term transient events
- Long-term impulse events
- Single-event transients
- Single-event impulse

Long-term models are used to calculate the average noise exposure generated by a whole series of operations (e.g., aircraft operations around an airbase). These models are used primarily for long-range planning to avoid incompatible land uses. On the other hand, single-event models are used to determine the noise exposure from a single operation (e.g., the noise footprint of an open-air explosion). Single event models are used to avoid noise impacts from a particular mission or to address a complaint about a noise event that has already occurred.

Table 5-1 provides a list of noise models and their applicable timeframes, noise characteristics, sources, and uses.

5.1.4 TYPES OF OUTPUT

The output of the noise models fall into two general categories: noise contour maps and single events.

For long-term modeling, the output is in the form of noise contour maps and Figure 5-1 shows a typical noise contour map of and airbase generated by NOISEMAP. Each numbered contour line indicates points where the L_{dn} is expected to be approximately equal. Logically, the highest exposure, 85, occurs around the runway and the lowest exposure shown, 65, extends out under the flight tracks from takeoffs and landings.

Model	Timeframe	Characteristic	Source	Use
NOISEMAP	Long-term	Transient	Fixed and rotary-wing aircraft	Airbase noise exposure
Rotorcraft Noise Model	Long-term & single events	Transient	Helicopter s and tiltrotors	Airbase noise exposure
ROUTEMAP	Long-term	Transient	Fixed-wing	MTRs
MR_NMAP	Long-term & single missions	Transient	Fixed-wing	MOA, MTR, Special uses ranges
BoomMap	Long-term	Impulse	Sonic booms	Supersonic MOA ops
BNOISE2	Long-term & single events	Impulse	OD & large guns	Ranges and OD pits
SARNAM	Long-term & single events	Impulse/transient	Small arms	Firing range
MENU10	Single event	Transient	Fixed wing	Flyover noise levels
MENU11	Single event	Transients	Fixed wing	Ground run up noise levels
NMSIM	Single event	Transients	Fixed wing	Subsonic aircraft operations
PCBOOM3	Single event	Impulse	Fixed wing	Sonic boom analysis
SELCAL	Single event	Transient	Fixed and rotary-wing	Flyover noise levels
SIPS	Single event	Impulse	blast	Open detonation blast
NAPS	Single event	Impulse	blast	Open detonation blast
TNM	Long-term	transient	Road traffic	Highway and road noise exposure
RWNM	Long-term	transient	Trains and guided rail vehicles	Rail operations, yard and tracks

Table 5-1 Noise Models and Their Uses

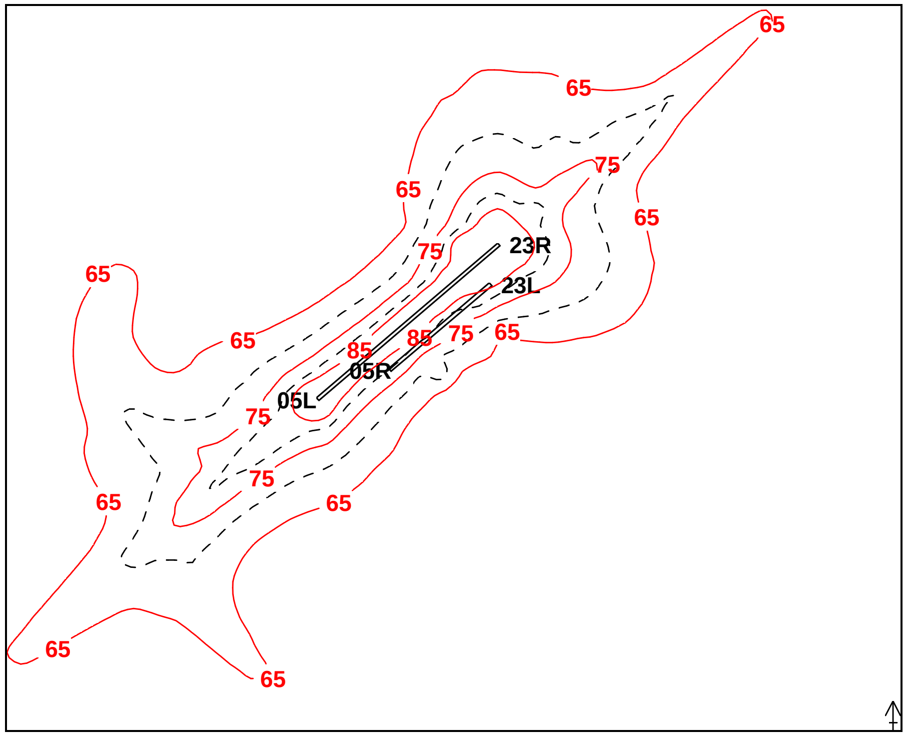

Figure 5-1 Typical Noise Contour Map

The noise models used most often by the DOD to produce noise contours are:

- **NOISEMAP and RNM** – for airbase noise
- **MR_NMAP** – for aircraft noise in MOAs, Ranges, and MTRs
- **BoomMap** – for sonic boom exposures from air combat maneuvers
- **BNOISE2** – for large caliber and blast noise
- **SARNAM** – for small arms ranges

For single events, the DOD uses:

- **SELCAL** – for basic aircraft noise levels
- **NMSIM and RNM** – for aircraft flyovers
- **PCBoom3** – for sonic booms
- **BNOISE2** single event function – for large weapons and blast noise

- **SARNAM** single event function – for small arms noise

- **NAPS and SIPS** – for time-specific predictions of explosive blast noise

Many of the aforementioned noise models have been developed for specific circumstances such as airplanes, helicopters, weapons, and general transportation.

5.2 AIRCRAFT MODELS

5.2.1 LONG-TERM FIXED WING AIRCRAFT MODELS

NOISEMAP

The primary tool for evaluating military aircraft noise in the vicinity of an airbase or airfield is NOISEMAP. NOISEMAP is a suite of computer programs developed by the U.S. Air Force for prediction of noise exposure from aircraft flight, maintenance, and ground run-up operations. This section presents an overview of the capabilities and general usage of NOISEMAP.

NOISEMAP, its noise database NOISEFILE, and its related programs (BASEOPS, OMEGA10, OMEGA11, NMAP, and NMPLOT) have been developed over a number of years. The current version of NOISEMAP (7.0) (Plotkin *et al.*, 2001) combines the above programs and is suitable for operation on a personal computer.

The NOISEMAP computer program "flies" each aircraft along a defined flight track, using the power, speed, and altitude profiles defined for its takeoff, landing, or closed-loop pattern operation. This is accomplished by specifying the flight track and performance profile. The flight track is a projection onto the ground plane of the three-dimensional flight path of the aircraft while the performance profile defines the dynamic characteristics of the aircraft in terms of altitude, speed, and power versus distance from the start of takeoff roll.

In the program, the noise levels of a specific aircraft (or class of aircraft) at a given thrust are defined as a generalized function of the slant distance between the aircraft and the observer. The path of the aircraft in space is defined in the input data set so that the slant distance between the aircraft and observer is known. The noise level versus distance data are used to determine the sound exposure level (SEL) at a specific ground location for a single operation. The program then computes the noise exposure from each aircraft flight at a grid of points on the ground. In the end, the noise exposure (primarily defined as DNL) at a ground location resulting from aircraft flight operations is a function of the SEL produced by the individual aircraft and the number of such aircraft operating during daytime and nighttime periods; the total aircraft flight noise exposure is thus the summation of the noise exposure from all operations of all aircraft on all flight paths.

NOISEMAP also computes noise exposure due to maintenance and preflight ground run-up operations. This is accomplished by specifying the run-up locations and run-up engine power profiles. The run-up power profile defines the characteristics of an engine run-up in terms of power setting and duration at each setting, magnetic heading of the aircraft, and any degree of noise suppression. The noise levels of a specific engine/aircraft combination at a given thrust are defined as a generalized function of the slant distance and directivity angle between the run-up location and the observer. The noise level versus distance and angle data are used to determine the A-weighted sound level (AL) at a specific ground location for a single run-up. The program then computes the noise exposure from each run-up at a grid of points on the ground. The DNL at a ground location resulting from aircraft ground run-up operations is ultimately a function of the AL produced by the individual run-ups, the duration of individual run-ups, and the number of operations occurring during daytime and nighttime periods.

NOISEMAP 7.0 also allows for modeling the effects of topography and ground impedance (Czech and Plotkin, 1998). Many airports are in surroundings where the ground is not a nominal soft surface (for example, propagation paths over water, which is an acoustically hard surface, are common) and some airfields are in surroundings where the ground is not flat. The understanding of sound propagation over ground has improved considerably over the past two decades, and the availability of topographic data in digital form made the practical application of this technology feasible. A working group of the North Atlantic Treaty Organization Committee on the Challenges of Modern Society of (NATO/CCMS) evaluated this question and determined that these effects could cause differences of up to 5 to 10 dB, and that practical applications are feasible. NOISEMAP 7.0 incorporates the algorithms developed through this NATO/CCMS effort (Plotkin, *et al.*, 1997).

Additionally, NOISEMAP has a number of subprograms in its arsenal. The BASEOPS subprogram is used by operators to input airfield and aircraft operational data in order to generate noise level versus distance data specific to the given airfield elevation, average temperature, average humidity, aircraft type, power setting, and operations. OMEGA10 is executed to develop SEL versus distance curves for aircraft flight operations, and OMEGA11 is executed to develop AL versus angle and distance for ground maintenance and run-up operations. The combined operational and noise data are then used as input to the NMAP subprogram which generates a grid of noise exposure values (normally in terms of DNL) on the ground at the user-defined spacing and at specific points defined by the user. The grid values are then further processed by the NMPLOT subprogram to produce noise contour maps (Figure 5.1) for the given set of airfield operations and conditions. Note: Data files that pass among the different individual programs are standardized to what is called the NoiseMap Binary Grid File Format (Wasmer, 1993).

It should also be mentioned that, in order for NOISEMAP to model the effects of terrain, additional data are needed to describe the elevation and impedance of the surface in the vicinity of the airbase. This elevation data are easily obtained from USGS but, at the time of this writing, no tools were available to prepare impedance files. However, the file structure is well defined and can be constructed from available ground cover data. It is important to note that it is not necessary to prepare detailed impedance files unless ground impedance varies significantly between soft and hard surfaces around an airbase.

Integrated Noise Model (INM)

The Federal Aviation Administration has also developed a model for analysis and estimation of aircraft noise around an airport. The Integrated Noise Model (INM) (Fleming *et al*., 1997) is similar to NOISEMAP in that it predicts the long-term average community noise levels for civilian aircraft operations. Output from INM is also provided in NMPLOT format so that the noise prediction from both models can be combined. Therefore, the primary difference between these models is that NOISEMAP is normally used for military aircraft and INM for commercial and civilian aircraft.

ROUTEMAP

Military aircraft routinely conduct low-altitude, high-speed training operations along Military Training Routes (MTR). The coordinates of the route centerline and the route width define an MTR and they are grouped into three sub-types: visual routes, instrument routes, and slow-speed (<250 knots) low-altitude routes. MTRs are continually changed because of the need to fly over a variety of terrain, changing requirements of weapon systems and tactics, and encroachment from underlying land uses on existing routes. DOD environmental policy requires an environmental assessment or impact statement to be filed whenever there is a change in air base operations or air space requirements on MTRs. The DOD also publishes a guide entitled “Area Planning – Military Training Routes – North and South America (AP/1B)” which contains the definitions of and operating instructions for all MTRs in the CONUS. This document defines each MTR by airspace segment and lists the latitude and longitude of the start and end points, the altitude profile (floor and ceiling), and the route width. Special operating procedures describe avoidance areas and additional terrain-following instructions. To model the noise exposures from these operations, the U.S. Air Force developed the ROUTEMAP computer model (Lucas and Plotkin, 1988).

The development of ROUTEMAP was based on a series of studies on MTR noise propagation (Plotkin and Croughwell, 1987; Plotkin, 1987; Plotkin *et al*., 1988; Molino *et al*., 1987; Speakman, 1987). Additional MTR noise studies have refined the algorithms for the computation of lateral attenuation (Speakman and Berry, 1992) the statistical distribution of aircraft flight tracks (Plotkin *et al*., 1992) and the Onset Rate-Adjusted Monthly Day-Night Average Sound Level (L_{dnmr}) metric (Bennett *et al*., 1992; Stusnick *et al*., 1992; Stusnick *et al*., 1993). The L_{dnmr} is the recommended metric for MTR noise analysis since it accounts for the potentially high onset rates of the noise and the sporadic nature of the operations.

ROUTEMAP models the noise exposure distribution along the cross-section of the MTR. The model has individual modules that allow the user to define MTR inputs, calculate noise exposures, and generate reports and graphs. The input module is used to construct the operational scenarios for an MTR by specifying the airspace components (segments) and aircraft flight parameters. The airspace parameters used by ROUTEMAP include the MTR segment width and the aircraft altitude and the user can also define how the operations are distributed within the route. For instance, one can model a narrow distribution, which is representative of long-range bombers using electronic navigation, or a widely dispersed distribution more typical of tactical aircraft using visual navigation and terrain masking.

The user must also enter the types and number of operations occurring for each route segment. Once input, the aircraft operations data for each MTR are stored in a single file, organized by individual airspace segments. The calculation of the noise exposure is based on a specialized version of U.S. Air Force's NOISEFILE database that contains noise data from high-speed, low-altitude flights. Computations are restricted to the actual measured conditions since the noise characteristics are complex for high-speed (as discussed in Chapter 4).

Military Operating Area and Range Noise Model (MR_NMAP)

The USAF developed a general-purpose computer model for calculating noise exposures occurring away from airbases, since aircraft noise is an issue not just along MTRs but also within Military Operating Areas (MOA) and ranges. This model is called MOA Range NOISEMAP or MR_NMAP (Lucas and Calamia, 1996) and it expands the calculation of noise exposures away from airbases by using algorithms from both NOISEMAP and ROUTEMAP. MR_NMAP uses two primary noise models to calculate the noise exposure: track operations and area operations. Track operations are for operations that have a well-defined flight track (such as MTRs, aerial refueling, and target bombing tracks) and area operations are for activities that do not have well defined tracks but occur within a defined area (such as air-to-air combat within a MOA).

The program has a user interface, MR_OPS, for the development of the input data. For track operations, input requirements are the same as for ROUTEMAP though more than just MTRs can be modeled. For area operations, the model allows flexibility: if little is known about the airspace utilization within a MOA, then the MOA boundaries can simply be used and the operations are uniformly distributed within that defined area. However, if more is known about how and where the aircraft fly within the MOA, sub-areas can be defined within the MOA to more accurately model the noise exposure.

Once the airspace is defined, the user must describe the different types of missions occurring within each airspace segment. Individual aircraft missions include the altitude, distribution, airspeed, and engine power settings. These individual profiles are coupled with airspace components, and the operational rates are then defined.

Finally, once the airspace and operational parameters are defined, the noise exposure can be calculated. MR_NMAP can calculate any of the following noise metrics: L_{dnmr}, L_{eq}, L_{dn}, CNEL, L_{Amax}, SEL, and SEL_r (rate adjusted SEL). The model calculates these noise metrics either for a user-defined grid or at user-defined specific points. The grid calculation can be passed to NMPLOT to plot the noise contours and the specific point calculation generates a table that provides the noise exposure itself and the top contributors.

<u>Long Range Helicopter Noise Models</u>

Although the DOD's NOISEMAP and the FAA's INM models include helicopter noise calculation routines, they do not properly account for the unique noise characteristics of helicopters and tilt-rotor aircraft (as discussed in Chapter 4). To address this limitation, NASA has led development of the Rotorcraft Noise Model (RNM) (Lucas and Marcolini, 1997). RNM is a computer model that predicts far-field helicopter and tilt-rotor noise for single event or multiple vehicle operations whereby vehicle operations are quantified along a set of user defined vectored flight tracks and profiles. As with NOISEMAP, a user enters this operational data through BASEOPS. The vehicle flight is simulated in a time-based domain along the defined flight track, and the rotorcraft noise is analytically propagated through the atmosphere. Noise predictions are calculated on a uniform mesh and then transformed into ground noise contours (using a myriad of noise metrics) to be employed in community noise impact assessments. These contours are in NMPLOT format and can easily be integrated with output from NOISEMAP, INM, and MR_NMAP. Noise predictions can also be made at specific receiver locations for detailed investigation of noise characteristics and noise level time histories.

At the core of RNM is the acoustic source definition of the vehicle in terms of noise hemispheres. The RNM database includes a collection of noise hemispheres derived from dedicated flight test measurements across the typical operational envelope for numerous rotorcraft. Through the joint efforts of NASA, the U.S. Navy, and NATO, the broadband source noise measurement database has been developed.

RNM also has the capability to accept analytically generated noise hemispheres for multiple noise sources, both broadband and pure-tone. These analytical data may be created using computational fluid dynamics models and then interfaced with RNM. RNM will perform the acoustical atmospheric propagation for a given vehicle and create ground noise predictions, detailed time history predictions, and other research focused output data.

<u>BoomMap</u>

BoomMap (Plotkin *et al*., 1992) calculates the long-term sonic boom exposures from supersonic operations within a MOA. The model is based on a series of four monitoring efforts at White Sands Missile Range, New Mexico (Plotkin *et al*., 1989). From these monitoring studies, it was determined that the noise exposure from the sonic booms is governed by the airspace boundaries and can generally be described by elliptical contours. The metric calculated by BoomMap is the C-weighted Average Day Night Sound Level (CDNL). The model uses currently defined airspace boundaries or user defined boundaries, along with a distribution of aircraft type and monthly operation rates within the airspace. Single or multiple ellipses can be used to best describe the airspace utilization. From these simple input data, the model calculates the CDNL on a grid of points in the NMPLOT Binary Grid Format, which is compatible with NMPLOT.

5.2.2 SINGLE EVENT AIRCRAFT NOISE MODELS

NOISEFILE data

The U.S. Air Force has developed two simple programs to access the basic aircraft noise data in the NOISEFILE database. One program, MENU10, accesses the flight noise and the other, MENU11, accesses the ground run-up noise. With MENU10, a user can select an aircraft and the desired engine power setting, airspeed, temperature, and relative humidity to obtain the noise versus distance curves as calculated by NOISEMAP's OMEGA10 propagation algorithm. The noise curves are then provided in air-to-ground and ground-to-ground modes. The calculated flyover noise levels can be viewed in the following metrics: SEL, L_{Amax}, and EPNL.

With MENU11, a user can select an aircraft and specify the desired engine power setting, temperature, and relative humidity to obtain noise versus distance curves in angle increments of 10 degrees about the aircraft. The OMEGA11 algorithm calculates these noise levels and, for the given parameters, noise levels are then provided in the following metrics: L_{Amax}, $L_{Amax,T}$, and PNLT.

NMSIM

From the research involved with the development of the topographic effects algorithms for NOISEMAP 7.0, a single-event aircraft noise model was developed by Wyle Laboratories, Inc (Plotkin, 1999). The original development of this model focused on the calculation values within the new algorithms. However, it was quickly noticed that this analysis tool could be used to simulate the noise from an aircraft flyover but the model requires more detailed source data than is currently used by NOISEMAP. The source data requirements are similar to RNM in terms of the dynamic directivity except for an assumption of symmetry about the aircraft centerline. Along with this additional requirement, NMSIM uses a more detailed, 1/3-octave band propagation algorithm. The model can be used to generate animated simulations of aircraft noise for a given area and the U.S. Air Force and the National Park Service have used this feature to visually demonstrate noise propagation for an aircraft flyover.

Rotorcraft Noise Model (RNM)

The RNM can also be used to calculate the noise footprint and specific location time histories from a single flight profile. In the single event mode, rotorcraft profiles can be developed to minimize total noise exposures or to reduce noise at specific locations. For this mode, RNM uses the same propagation algorithms but a more detailed track profile can be used.

PCBOOM3

PCBoom3 is a PC-based computer program that computes single-event sonic boom footprints and signatures from any supersonic vehicle exercising any maneuver in a realistic atmosphere, including winds (Plotkin, 1996). This model has been verified with field measurements and accurately accounts for focusing of the sonic boom from aircraft maneuvers (ref JASA). The program is operated through a menu interface which simplifies its use and the presentation of results. The user specifies the aircraft, the maneuver, and atmosphere and the primary output is the sonic boom footprint in terms of contours of equal overpressure (or other amplitude metric) on the ground, relative to the aircraft's position. PCBoom3 also generates sonic boom signatures, the pressure-time histories, and spectra of booms at the ground.

Figure 5-2 provides an example of the footprint output from PCBoom3. This figure has been reproduced from a paper given by Plotkin (2000) and it represents the typical ascent boom footprint for a launch vehicle.

Personnel who are planning specific supersonic missions where sonic boom impacts may be an issue or persons who are investigating sonic boom incidents should use PCBoom. The model can be used to calculate the sonic boom footprint from simple events such as a functional flight check for an F-16C, to more complicated events such as the launch of a Titan IV rocket. While the program is relatively simple to operate, it provides access to analysis which requires an understanding of sonic boom phenomena in order to properly interpret the results.

Carlson's Simplified Sonic Boom Model

Another model for single event sonic booms is referred to as Carlson's Sonic Boom model (Carlson, 1978). This model is based on experimentally derived relationships for all of the major factors controlling sonic boom generation and propagation. Although this model is restricted to calculating sonic booms from a steady state, supersonic flight, it provides useful estimates for focused sonic booms by simply multiplying the overpressure by a factor of two to five. The model only requires basic inputs of flight parameters and the sonic boom characteristics can be calculated from graphs and a calculator. There are several computerized versions of the model such as Boom10 (USAF) and CaBoom (Wyle).

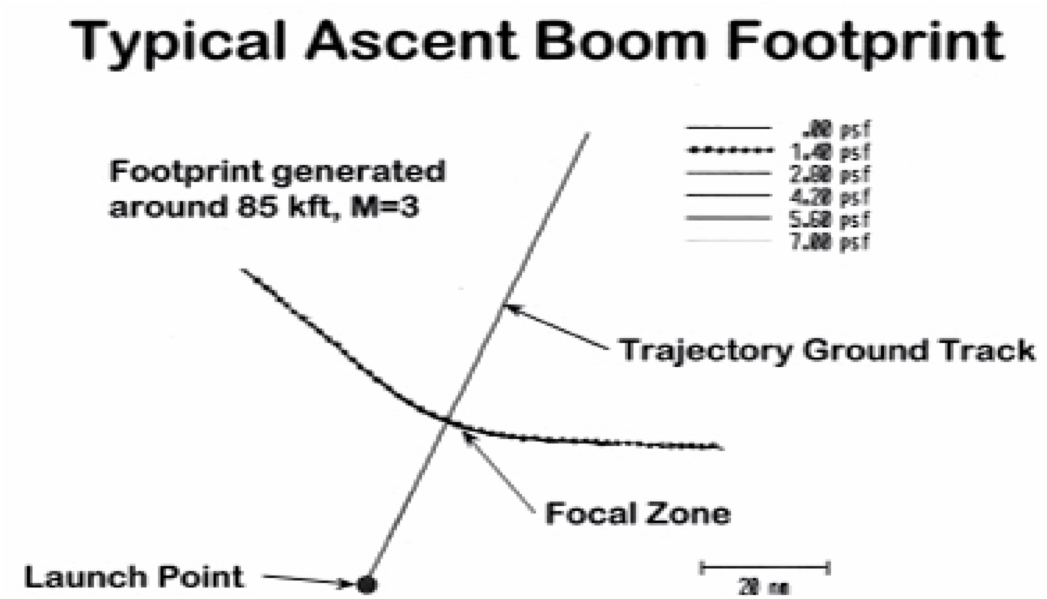

Figure 5-2 Example of a Sonic Boom Footprint from PC3Boom

5.3 WEAPONS NOISE MODELS

5.3.1 LONG-TERM WEAPONS NOISE MODELS

Military training and testing operations of surface based weapon systems may cause significant noise impacts on the surrounding area. One element of an effective noise management strategy is the ability to accurately forecast the noise exposure and assess community response. Proper evaluation of the impacts of weapon noise on humans and animals requires knowing the characteristics of the noise exposure received by the community and the environment.

Accurate assessment of the noise effects in any given scenario requires knowledge about the noise characteristics of these weapons and the modeling algorithms, which can model both short- and long-range propagation distances on the weapon noise. Also important is the ability to model the noise exposure from just a single firing of a weapon to annual operations of weapon training. This section will discuss the primary surface-based weapon system noise models available. Note: Some of these models include the ability to calculate both single event and long-term noise metrics.

BNOISE2

The BNOISE2 computer program, which has been a primary tool for blast noise assessment for over twenty years, is being replaced by BNOISE2 but contour maps made with BNOISE2 are nearly identical to those made with the original BNOISE.

BNOISE2 satisfies several requirements that are crucial to preserving military training capability. The U.S. Army's Installation Operational Noise Management Plan (IONMP) requires inclusion of noise contours, as do other land use and management plans of the other services. BNOISE2 directly addresses the Conservation User Requirement dealing with "Mitigating Army Unique Impacts."

BNOISE2 is an Army-developed computer program which calculates and displays blast noise exposure contours resulting from specified operations involving large guns and high explosive charges. BNOISE2 includes considers the type of weapon and ammunition, the number and time (day/night) of rounds fired, range attributes, weather, and assessment procedures and metrics. It accounts for the spectra and directivity of both muzzle blast and projectile bow shock, which facilitates accurate calculation of propagation and sound frequency weighting. The source model parameter values are based on empirical data while the propagation algorithms are based on sophisticated calculations and experimental data. Available metrics include sound exposure level (SEL) and day-night noise level (DNL). Additionally, BNOISE2 also accounts for the effects of land-water boundaries and terrain.

BNOISE2 features a point-and-click graphic user interface with pull-down menus and on-line help, and is designed to maximize user productivity. Information (e.g., the types of weapon and ammunition, the locations at which the firing takes place, the number of shots during daytime and nighttime, etc.) is entered into an activity table and required information regarding the guns, ammunition (source models) and weapon ranges is stored in databases which are chosen via "pick lists." A library of database records (including weapons, metrics and frequency weighting schemes) is included with the program. The propagation algorithm is used to calculate sound levels at each node of a user-defined geographical grid and the resulting array of noise level values is converted to contours and prepared for display by NMPlot.

Noise assessment capability is an essential part of an encroachment management program and can help an installation avoid future noise problems and the need to purchase noise-impacted land. Along with assessing long-term community noise impact, BNOISE2 can also be used to:

- Examine noise levels due to a particular firing event
- Defend against noise complaints and damage claims

- Plan range operations

- Explore noise ramifications of range design options such as siting and orientation

Figure 5-3 shows noise contours for Fort Carson, Colorado that have been created by the BNOISE2 model. Notice how, over time, the total cumulative noise exposure increased somewhat and the center of mass for the exposure shifted toward the south. This was due to the opening of new tank gunnery ranges in the southernmost part of the installation.

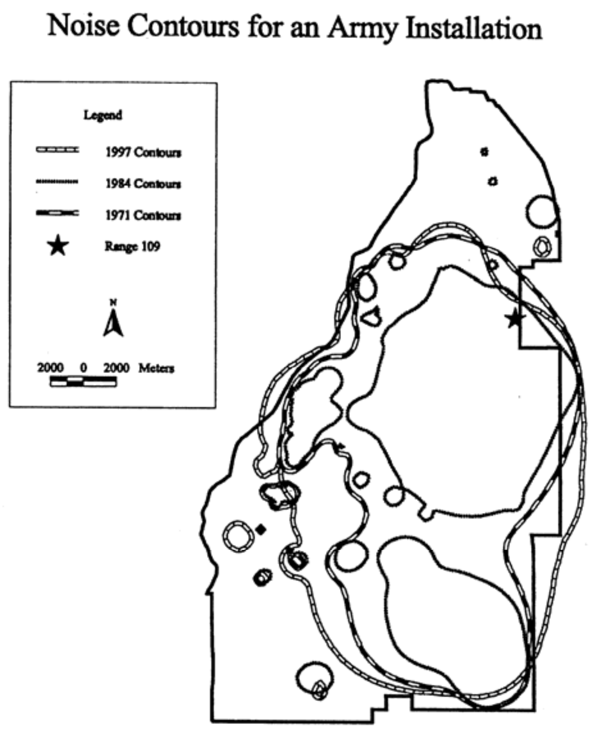

Figure 5-3 Fort Carson, CO BNOISE2 Contours

<u>SARNAM</u>

Noise from small arms ranges often annoys people living in the surrounding community. SARNAM is a computer model that provides the capability to calculate and display noise level contours for firing operations at small arms ranges. It includes consideration of type of weapon and ammunition, number of rounds fired, time of day, and range attributes such as size and barriers, metrics, and assessment procedure. It accounts for spectra and directivity of both muzzle blast and projectile bow shock which facilitates accurate calculation of propagation and of sound attenuation by barriers. Source model parameter values are based on empirical data and the propagation algorithm assumes a moderate downwind propagation condition based on sophisticated calculations and experimental data. SARNAM offers a choice of sound exposure level (SEL) and day-night noise level (DNL) metrics and a variety of frequency weightings are also available. To account for the added annoyance from small arms ranges, a 12 dB penalty is added to the SEL of small arms noise. This penalty is not assessed for "rapid firing" which is defined as an aggregate firing rate greater than 30 shots per second.

The program can be used to assess long-term community noise impacts, examine noise levels due to a particular firing event, plan range operations, and explore potential noise impacts of range design options such as siting, orientation, barriers, and safety baffles.

It features a user-friendly, point-and-click graphic user interface, pull down menus, and on-line help, and is designed to maximize user productivity. A library of database records (including military and commercial weapons, metrics, and frequency-weighting schemes) is included as part of the software package and the user can define and store additional entries. Display of calculated noise contours is via NMPLOT.

SARNAM can satisfy several requirements that are crucial for preserving military training capability including the protection of endangered and threatened species. Many uses of SARNAM do not require an acoustics expert but would require extensive knowledge about training procedures, weapons, and a basic familiarity with noise characterization metrics.

Noise contours generated with SARNAM are similar to those generated with BNOISE2; the primary difference is the size of the contours. SARNAM contours span hundreds of meters while BNOISE2 contours span kilometers.

5.3.2 SINGLE EVENT BLAST NOISE MODELS

Ray Tracing Models

For blast noise, there are several types of modeling approaches that can be used varying from simple tables to advanced computational models. For predicting the likelihood of high blast levels in a particular direction from an explosion, a ray-tracing model published by the Ballistic Research Laboratory (Perkins and Jackson, 1964) provides a good, general guidance of noise levels. This early model is similar to Carlson's model for sonic booms. Figure 5-4 shows the three examples of ray tracing diagrams for a particular direction. These diagrams show areas where sound can be expected to be higher than or lower than sound propagating in a homogeneous atmosphere.

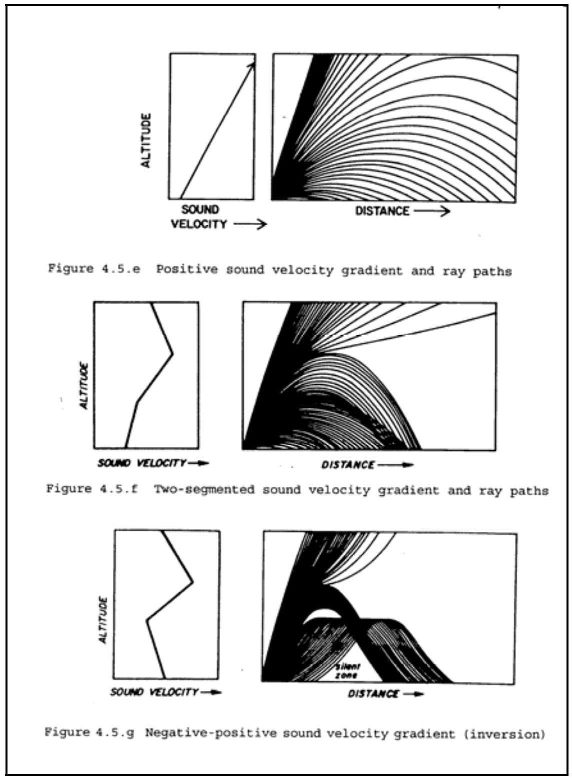

Figure 5-4 Three Meteorological Conditions Associated with Ray Tracing Models

However, since blast noise is greatly influenced by atmospheric conditions, more detailed ray-tracing models are required to calculate focus regions and shadow zones in near real-time. Ray tracing methods depict the propagation path of the sound and include the influence that atmospheric variations have on propagation but, depending on the vertical variation of the sound speed through the atmosphere, sound will either be refracted upwards or downwards. Thus, ray-tracing models require detailed information about the variations of temperature and wind with altitude. Once this atmospheric data is provided, along with the source strength of the blast itself in Net Explosive Weight (NEW), the model can calculate the noise exposure for that particular blast in that particular atmospheric profile. For forecasting potential focal areas, a calculation is only good under stable atmospheric conditions and generally within one hour of the atmospheric data utilized in the calculation.

Currently, two ray tracing models are available for single event blast noise: Noise Assessment Prediction System (NAPS) (Dietenberger *et al*., 1991) and Sound Intensity Prediction System (SIPS) (Gholson, 1974). These models are used to forecast potential adverse noise exposures before an open detonation is conducted. Figure 5-5 shows a typical output from NAPS. If a focus region is shown to occur at or near a sensitive receptor, then the open detonation operation should be delayed until atmospheric conditions are more favorable. NAPS is employed at the U.S. Army's Aberdeen Proving Ground, Maryland, and SIPS is employed by the Naval Surface Weapons Center at Dahlgren, Virginia and at the Air Force's Utah Test and Training Range.

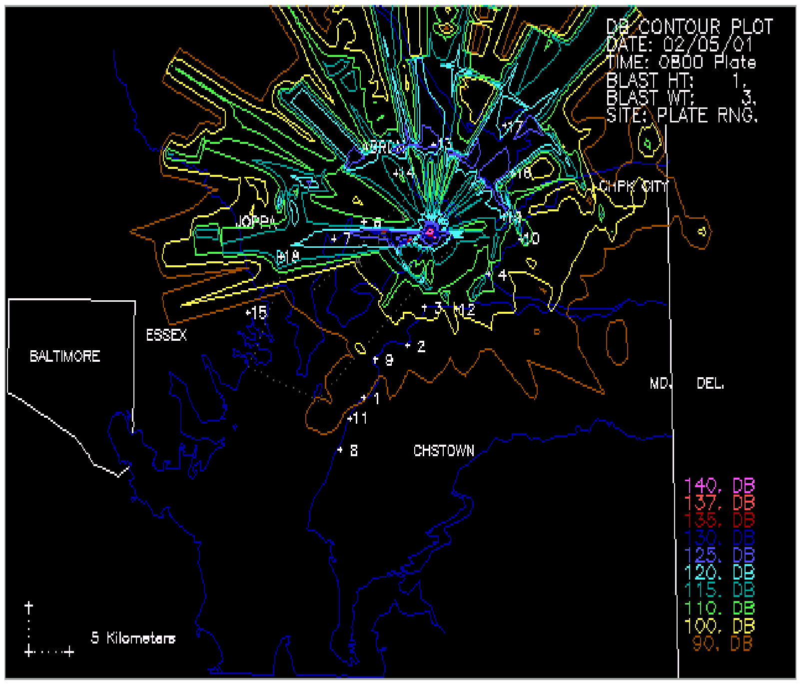

Figure 5-5 Typical Pattern of Prediction from NAPS (8:00 AM in February)

Hybrid Models for Blast Noise

Some military acoustics experts have found better prediction from the mathematically more complex Parabolic Equation (PE) (e.g., Dobrey *et al*., 1994) or Fast Field Program (FFP) (e.g., Barnes, 1994). A model known as LARRI (West *et al*., 1996) was developed for use at artillery and tank gunnery ranges in the UK and it combines ray tracing predictions with these more complex predictions. At the time of writing, the DOD was not using FFP or PE models for predicting blast noise. A tutorial on FFP was published by West *et al.* (1991) and on PE by West *et al.* (1992).

Use of BNOISE2 and SARNAM to Predict Single Events

The use of average noise levels over a protracted time period generally does not adequately assess the probability of community noise complaints. Using BNOISE2 to assess the risk of noise complaints from large caliber impulsive noise resulting from testing and training activities, ex. armor, artillery, mortars and demolition activities, in terms of a single event metric, either peak sound pressure level [PK 15(met)] or C-weighted sound exposure level (CSEL). The metric Pk 15(met) accounts for statistical variation in received single event peak noise level that is due to weather. It is the calculated peak noise level, without frequency weighting, expected to be exceeded by 15 percent of all events that might occur. To account for normal (average) weather conditions the BN3.3 Weather Emulation is selected in the BNOISE2 calculation. If there are multiple weapon types fired from one location, or multiple firing locations, the single event level used should be the loudest level that occurs at each receiver location.

Using SARNAM to assess the small arms noise from testing and training activities, ex. M-16 rifle, M-9 pistol or M-2 machine gun activities, in terms of a single event metric, either peak sound pressure level [PK 15(met)] or A-weighted sound exposure level (CSEL). The metric Pk 15(met) accounts for statistical variation in received single event peak noise level that is due to weather. It is the calculated peak noise level, without frequency weighting, expected to be exceeded by 15 percent of all events that might occur. The propagation algorithm assumes a moderate downwind propagation condition based on sophisticated calculations and experimental data. If there are multiple weapon types fired from one location, or multiple firing locations, the single event level used should be the loudest level that occurs at each receiver location.

5.4 GENERAL TRANSPORTATION

For general traffic (trucks, automobiles, etc.) noise exposure modeling, the recommended model is the Federal Highway Administration's Traffic Noise Model (TNM). This program is designed for assessing highway traffic noise impacts at nearby areas and aids in the design of highway noise barriers.

TNM includes noise levels from automobiles, medium and heavy trucks, buses, and motorcycles, and models the influence of four basic pavement types. TNM also includes the influence on speed from various traffic-control devices and the effects of multiple reflections between parallel barriers or retaining walls. Additionally, its propagation algorithms account for the effects of topography, ground cover, barriers, buildings, and trees.

A user defines the road conditions, traffic counts, and local topography for the model input. The model then calculates the received noise at designated locations in terms of the hourly A-weighted equivalent sound level (L_{Aeq1h}), DNL, and CNEL. The model also computes contours in terms of sound levels, noise reduction from barriers, and level differences between two barrier designs.

For railway noise, there currently is no established computer model – although the Federal Railway Administration is trying to develop the Railway Noise Model (RWNM).

5.5 ASSESSMENT SYSTEM FOR AIRCRAFT NOISE (ASAN)

The Assessment System for Aircraft Noise (ASAN) was a suite of computer programs developed by the Air Force for environmental noise assessment and planning purposes (Ort, 1998). The program was designed specifically for the assessment of noise and sonic booms from aircraft operations along military training routes (MTRs), military operating areas (MOAs), and ranges. However, ASAN had additional capabilities including Geographic Information Systems (GIS) technology, relational database management software capabilities, the availability of national digital databases, improved aircraft noise prediction models, and the inclusion of new models to predict the effects of aircraft noise on humans, animals and structures. Because of these capabilities, ASAN could be used to perform many other steps necessary to satisfy the requirements of the noise element in National Environmental Policy Act and environmental impact analysis documents. ASAN is no longer supported by the USAF and has been replaced by the Environmental Toolbox Effects Models.

5.6 ENVIRONMENTAL TOOLBOX EFFECTS MODELS OVERVIEW

The Toolbox is an evolution of the Assessment System for Aircraft Noise (ASAN) program that was initiated for the purpose of calculating noise impacts to receivers under military airspace. ASAN was developed as a robust analytical tool that defined aircraft missions and scenarios and using noise models, calculated exposure levels to various receivers within the boundaries of the airspace being analyzed. The program took the noise exposure levels further and applied these levels to impact models to determine potential issues of aircraft operations on human, animal, and structure receivers. The receivers were geographically located and a Geographic Information System (GIS), the Geographic Resources Analysis Support System (GRASS), was used for calculation and display of the receivers, airspace, and some land-use layers. The ASAN system incorporated a Graphical User Interface menu item for update of the airspace database which was obtained from National Oceanic and Atmospheric Administration (NOAA). Updates to the other GIS layers population, animal, towns, boundaries, and other value-added layers) required GRASS and programming experience. Point receivers were manually entered into the database on a scenario-specific basis and were not incorporated into a master database table where they would accumulate and be available for access by other analysis scenarios. Static data elements (locations of towns) are stable; however human demographics, military airspace, animal populations, land use categories, boundaries and ownership of Federal and private lands are dynamic. Each of these categories has a different change cycle, and for any impact analysis to be valid, they must be correctly placed spatially as well as having the correct population attributes.

ASAN was implemented using Oracle. For every scenario generated, ASAN developed all the tables needed to capture all of the mission, GIS, and receiver information. This meant that for every scenario, there were duplicate tables created in the database that contained information for each scenario. Copying and creating these duplicate tables was an easy way to provide recall of any particular scenario. As more scenarios were developed, the more copies of these tables were made, until the system hit physical limits of memory and hard disk space. Management of all these tables, i.e., keeping track of the tables and how they were linked to each individual scenario required operators with skills in Oracle database administration and the UNIX operating system.

The next evolution of ASAN included porting ASAN to ESRI's ArcView using a combination of AVENUE scripting and C++ coding. The implementation proved to be an improvement on the original ASAN operation since it could now work on a PC vs. a UNIX platform. The user was required to have a familiarity with GIS data and how to work ArcView. The receptor datasets were sourced from the original ASAN. Periodic updates of airspace data (Digital Aeronautical Flight Information File [DAFIF]) a monthly subscription to the National Geospatial Intelligence Agency (NGA) DAFIF CDROMs. GIS datasets were imported in a Shapefile format and the user was responsible for deleting old, and adding new datasets.
The common thread in all of the ASAN and Toolbox implementations up to this point was data in the areas of interest. The program accurately calculates impacts to receivers, given that the location and presence of the receptors are known and accurate.

5.6.1 ENVIRONMENTAL TOOLBOX EFFECTS MODELS REQUIREMENTS

The Toolbox directly supports the Air Force's ability to conduct flight operations in military restricted airspace, which includes Military Training Routes (MTRs), Military Operating Areas (MOAs), and range airspace. Performance of this mission is dependent upon the ability to describe and assess (in a timely and defensible manner), the magnitude and impact of air quality and subsonic and supersonic noise. The models incorporated into the Toolbox are web-based, and draw on a common database of the most current natural and cultural features found under the Special Use Airspace (SUA). Noise receptors are defined as human and animal habitat/concentration sites, and structures located under or within one mile of the boundaries of a SUA, and which are generally considered to be likely (under some conditions) to be adversely affected by, or to adversely react to, subsonic and/or supersonic aircraft noise. The Toolbox database contains noise receptors (associated with either a point or an area) used to generate predictions of noise conditions and reactions of receptors to those conditions.

5.6.2 TOOLBOX DATA REQUIREMENTS

The Toolbox was designed to provide a single interface portal to a variety of air quality and noise models that support environmental analysis. The user, when running a scenario in the Toolbox, will assume that whatever data is presented for selection or is being used by the models will be qualified data from authoritative sources. Finding this data is difficult because the sources are dispersed, and range from commercial to Federal Government. There are several categories of data used in the Toolbox. Those categories are:

- Source data used for display and context for the mapping displays
- Data input by the user for air quality/noise analysis
- Source data used for noise analysis
- Source data used for air quality analysis

The main factor in using and collecting this data is currency and maintenance of the data. The strategy used to maintain this information will be to use sources that are public, accessible, obtainable, authoritative, and preferably at no cost.

5.6.3 DATA VOLATILITY

The Toolbox has been designed to use both static and dynamic datasets. Datasets obtained for the Points of Interest data can be extremely volatile since there are a variety of different variables, which directly affect biological and ecological systems. Datasets representing the commercial air corridors and the MTRs are less volatile, but are updated on a periodic basis. The least volatile datasets are those, which have a geological or geographical permanence i.e., political boundaries, highways, rivers and waterways, and ecological and cultural boundaries. Points of Interest data required for the noise models within the area represented by the route centerline and buffer zones for the entire extent of the MTRs are volatile. This data must be updated on a periodic basis, which can be several times a year. Most of the cartographic data is not volatile, and will require almost no attention during the lifecycle of the current revision of Toolbox. Periodic updates of the datasets would be required for the data to remain current. These categories will be developed and discussed in further detail below.

5.6.4 DATA FOR MAPPING AND DISPLAY AIRSPACE DATA

Airspace data may consist of MTRs, and MOAs. MTRs are characterized spatially with a route centerline, and buffer zones extending at variable distances away from the route centerline, which define the MTR boundary. MOAs are either one polygon, or several contiguous polygons that are irregular in shape and may be separated. The MTR routes are projected onto the surface topography of given regions as delineated by AP1B and included in the DAFIF, and the Toolbox database includes all noise sensitive sites and their attributes which are contained within the MTR boundaries. DAFIF information is published in a CD-ROM format and distributed to military subscribers every 28 days, and is also available over the web at: http://164.214.2.62/products/digitalaero/index.html

5.6.5 USER DEFINED AIRSPACE

User defined airspace is not a category of data that is available from authoritative sources, but is developed as a result of a user either entering the coordinates of the airspace via the forms or by interacting with a map. The airspace is not persistent because it is saved as part of an analysis project and is not added to the authoritative National Geospatial Intelligence Agency (NGA) airspace data for use by users of the Toolbox. The procedures of how User Defined Airspace would be implemented in terms of analysis are beyond the scope of this document and can be developed with subsequent tasking.

5.6.6 USER DEFINED INPUT

The data input screens for several stand-alone PC programs have been combined into one, unified web-based input screen that captures all required user input to run both air quality and noise analysis. Some of the user data required for air quality and noise analysis is very similar, which makes combining both user interfaces more efficiently and reduces redundancies. The input files are similar for each model, and the user has the option to select which models to run.

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CHAPTER SIX

NOISE MONITORING

The noise models described in Chapter 5 are the primary means of assessing the effect of military training noise on humans, animals, and structures. Because each model operates from a database of precise sound measurements, the maps generated with these models provide fast, inexpensive, and accurate predictions over large tracts of land. Nevertheless, there are some situations when actual sound measurements are needed. The measurement of noise environs is more expensive and labor intensive. This chapter lists those situations and describes the type of equipment available for each application.

Depending on the purpose of the monitoring, noise measurement can be:

- Short term with a technician present (e.g., several hours or a workday)
- Intermediate term with portable automated equipment and no observer (e.g., a few days to weeks)
- Long term with permanent noise monitors (e.g., years)

The American National Standards Institute has issued a standard for both short-term measurement with an observer (ANSI, 1993) and measurement without an observer (ANSI, 1992). In addition, the military departments have funded a significant amount of research on the design of permanent monitoring equipment. Some of this research is discussed later in the chapter.

6.1 PURPOSES OF MONITORING

The five general purposes for noise measurement are:

- Collecting precise reference data
- Assessing a specific or special noise environ
- Checking the predictions of a noise model
- Ensuring compliance with laws, regulations, or policies
- Mitigating noise and managing complaints

6.2 COLLECTING PRECISE REFERENCE DATA

When developing the database for the models discussed in Chapter 5, personnel must follow an exact procedure. For example, measurements for the NOISEFILE database for NOISEMAP require pilots to fly over a microphone array at a fixed altitude and at a specified speed or power setting. Even if something beyond control, such as the meteorological conditions, isn't within the specifications for the measurement protocol, personnel must wait for the right weather. The collection of a database for a model is generally performed by the Engineering Research and Development Center for weapons firing, the Air Force Research Laboratories for fixed-wing aircraft, National Aeronautics and Space Administration for rotorcraft or a experienced acoustical consultant (e.g., Wyle Laboratories) with specialized equipment

In contrast, physical monitoring of environmental sound can take place at any time, at any location, and for any length of time. For something like road traffic noise, the measurement period might be as short as the busiest hour of the day. In other situations, the period may be days, weeks, or years. Monitoring takes place in all kinds of weather with no control over when and where noisy military equipment is operating.

6.3 ASSESSING A SPECIFIC/SPECIALIZED NOISE ENVIRONMENT

Three situations in which assessment by noise measurement may be preferable to noise modeling are:

- Assessments for which models do not exist.
- Assessments for which models are inadequate.
- Assessments in which military noise is mixed with non-military noise.

6.3.1 ASSESSMENTS FOR WHICH MODELS DO NOT EXIST.

The major cost in noise modeling is collecting operational data. In some situations, it may be less work to take direct measurements than to collect the operational data. An example of an assessment for which modeling would have been more expensive than monitoring involved high levels of traffic noise at Fort Hamilton coming from highways in Brooklyn, New York (AEHA, 1980). Occupants of a few military apartments had complained that they were unable sleep at night. Although the Federal Highway Administration (FHWA) had a computer model for predicting traffic noise, collecting traffic data from the City of New York would have been more expensive than measuring the traffic noise directly.

Another situation when monitoring costs less than modeling is with OCONUS (outside the continental United States) installations where host nations may be unwilling or unable to supply operational data. For example, offices and billeting at Camp Eagle, Korea, are exposed to high levels of noise from F-4 aircraft operating out of the adjacent Republic of Korea Air Force base. The easiest way to assess this noise is monitoring.

6.3.2 ASSESSMENTS FOR WHICH MODELS ARE INADEQUATE

The models described in Chapter 5 are fairly robust and they predict well in most situations. However, there are some situations not covered by the models. For instance, when sound propagates over snow, much more sound is absorbed into the surface than with propagation over an open field. Conversely, when sound propagates over a hard surface, such as water, very little sound is absorbed. Acousticians lump the effects of different types of surfaces under the term, *ground impedance*. Until recently, DOD noise models did not account for impedance effects, and efforts to incorporate these variables are still ongoing.

An example of a situation in which the original BNOISE model was inadequate is the propagation of gun noise from the Army's Aberdeen Proving Ground (Maryland) to homes located on the opposite shore of the Chesapeake Bay. Unlike sound propagation over land (where the pressure wave decays relatively quickly), without ground or vegetation to absorb the sound, gunfire propagates very efficiently across the face of the water (White *et al*., 1993). In this case, physical monitoring gave a better estimate of exposure at homes located along the edge of the bay than did modeling with the original BNOISE.

6.3.3 ASSESSMENTS IN WHICH MILITARY NOISE IS MIXED WITH NON-MILITARY NOISE

On some occasions, a controversy may arise about whether military activities lead to an increase in a community's noise levels above the background sound level that would normally exist if the military weren't in the community. An example was the assertion of regulators in North Carolina that noise levels from an Army National Guard Aviation Support Facility (AASF) at Raleigh-Durham Airport was raising noise levels in a nearby park (AEHA, 1988). In this case, the sound monitors were set to collect successive 10 minute L_{eq} measurements and the technician kept a log of times when ARNG helicopters were operating. By calculating the L_{eq} from 10-minute periods without AASF activity and comparing it with the L_{eq} from 10-minute periods with AASF activity, it was possible to show that the sound environment was controlled by commercial airlines.

6.4 CHECKING THE PREDICTIONS OF A NOISE MODEL

Even when a model is considered to be adequate for assessing a particular environ, it may be necessary to check the predictions of the model. Three possible reasons to double check the accuracy of a model are:

- Initial validation of a model before release
- Questions about the accuracy of operational data
- A challenge from the public

6.4.1 INITIAL VALIDATION OF A MODEL BEFORE RELEASE

As part of the quality control measures when a new or updated model is created, it is often desirable to conduct a formal validation before releasing the model for general use. Validation, however, is an expensive process because of the need to monitor over a relatively long period to obtain an adequate statistical sample. Also, when dealing with the public, it is important to distinguish between validating a noise model and checking the predictions of a noise model. Checking predictions is a less rigorous process, and therefore, less expensive.

6.4.2 QUESTIONS ABOUT THE ACCURACY OF OPERATIONAL DATA

Environmental noise experts depend on airfield and range managers to provide accurate operational data. In turn, the airfield and range managers depend on the users to report properly those data. If that operational data come into question, noise monitoring may be needed for quality control.

6.4.3 A CHALLENGE FROM THE PUBLIC

Occasions may arise when communities or developers challenge the accuracy of a noise contour map and environmental sound monitoring may be useful in addressing such a situation. The needed duration of monitoring will depend on the day-to-day sound exposure level (SEL) variability (from changing number of operations and distance from the sources) at the site in question. Procedures are different for NOISEMAP, ROUTEMAP, SARNAM, and BNOISE2.

Some communities and developers have sufficient funds to bring in their own acoustical consultant to make noise measurements. This can be particularly troublesome because, as noted in Section 5.1.2, accurate noise monitoring requires much skill and experience and zoning boards and Federal judges do not have the background to distinguish between good and bad monitoring data. For example, in 1997 an environmental consultant hired by a developer near Fort Carson, Colorado decided to monitor the C-weighted DNL from tank gunnery noise by setting noise dosimeters to measure the C-weighted L_{eq}. The proper way to monitor the C-weighted DNL from weapons noise is to measure the CSEL of each gun shot and calculate the noise dose from the energy sum of individual events. By taking the "short cut" of the C-weighted L_{eq}, the consultant measured wind, aircraft, and every other low frequency event, thereby arriving at a spuriously high decibel reading. In this case, the Federal court refused to hear the plaintiff and Army experts were spared the difficulties of trying to educate a Federal judge on the intricacies of noise measurement.

To avoid these complicated situations, airfield and range managers are advised to take a proactive approach when the public challenges the accuracy of a noise contour. As explained in the following paragraphs, the approach will differ depending on the noise source.

6.4.3.1 CHECKING CONTOURS AT MILITARY AIRFIELDS

For military aircraft, the Air Force has developed a monitoring system incorporating statistical algorithms for determining the accuracy of noise monitoring (U.S. Air Force, 1978). This system is known by the acronym **NOISENET** and the statistical algorithms are known by the acronym **NOISECHECK**.

NOISENET consists of a network of semi-permanent noise monitors linked by a central desktop computer running interactive control software. The NOISENET system software is responsible for coordinating the acquisition, storage, retrieval, analysis, and reporting of noise data, noise complaint data, weather data, aircraft operations data, geographic data, and demographic data. The NOISENET system is to be utilized as a tool for assessing aircraft noise impacts, primarily in communities around airbases. The NOISENET system enables airbase planners to collect and maintain organized records of airbase flight operations, noise data, and noise complaint data. It can also serve as an assessment tool for evaluating noise impacts on communities and the relative effectiveness of noise abatement efforts. Consequently, NOISENET serves as a powerful public relations tool for use in public forums, complaint resolution, and legal defense. Additionally, NOISENET functions as a management system for noise and operations data collection and analysis in support of the AICUZ process for establishing noise contours around airbases and recommendations for land usage. NOISENET implements the NOISECHECK analysis methodology to validate or update airbase noise contours generated by the NOISEMAP noise modeling program on the basis of measured noise levels. Figure 6-1 illustrates the NOISENET conceptual process.

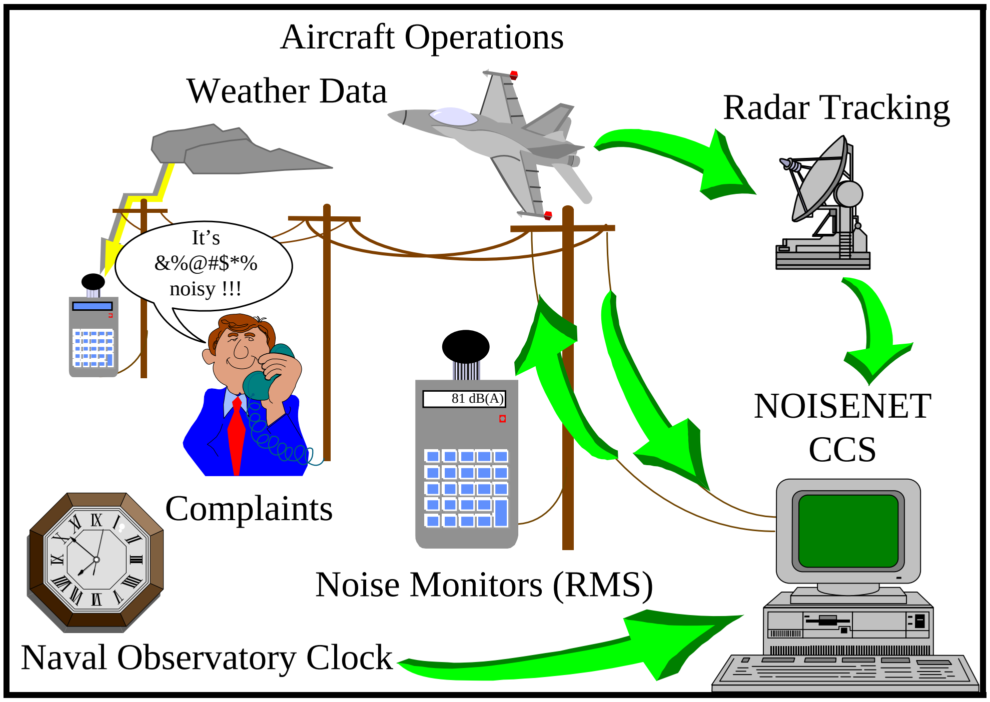

Figure 6-1 NOISENET Conceptual Process

The AICUZ process assesses the noise impact on areas around airbases using noise contours generated by the NOISEMAP computer model of aircraft operations noise. When the contours produced by NOISEMAP during the AICUZ process are challenged or verification of these predicted noise levels is sought, then the NOISECHECK procedure is implemented.

The NOISECHECK procedure involves a statistical comparison of the NOISEMAP-modeled noise data to measured noise levels around the airbase. In order to modify predicted noise contours, NOISECHECK proceeds with an iterative process of measurement, data analysis, contour adjustment, and contour validation to make the AICUZ noise predictions concordant with existing measured noise levels.

During this process, it is often necessary to obtain extensive supporting data relating to flight activity, airbase operations, and weather conditions to accurately account for factors contributing to the overall noise environment around the airbase. The resulting noise impact data produced by these monitoring efforts can be assessed in conjunction with community demographics and complaint data to assess specific land use incompatibilities and resolve specific noise problems. The resulting noise impact data can also aid in the development of operational procedures and abatement programs to minimize noise impacts in communities surrounding the airbase.

6.4.3.2 CHECKING CONTOURS IN AIRCRAFT CORRIDORS

Ambient sound levels in corridors used by military aircraft are generally quiet because they are located in rural or wilderness areas. So when a high performance aircraft flies the corridor, sound measurement instruments register a sharp, temporary increase in sound levels. However, it should be noted that other causes of sharp, temporary increases in sound levels may include birds, insects, and thunderstorms. So an effective way to distinguish increased levels due to aircraft from other sound sources is to locate several sound monitors in the corridor. For example, if a set of synchronized monitors is located on a line perpendicular to the flight corridor, a passing aircraft will register the highest levels on the closest and the lowest levels on the farthest monitor.

6.4.3.3 CHECKING CONTOURS FROM SMALL ARMS RANGES

Checking contours from small arms ranges poses a special challenge because the sound is impulsive. Unlike the continuous sound from aircraft, the impulsive sound from guns may be difficult to detect against the background of other sounds in the environment. Two common approaches are:

- Measure the level of individual events and compare with the single event prediction option in SARNAM
- Measure the A-weighted L_{eq} and compare with the SARNAM contour

Measuring Individual Events

During measurements with an observer, there is a choice of four common measures of small arms noise: A-weighted SEL, L_{max} A-weighting on fast response, linear peak, and A-weighted L_{eq}. There are two advantages and two disadvantages to SEL. The advantages are that the SEL is a measure of all the sound (i.e., the propellant blast, the ballistic wave, and reflections from ground, buildings or barriers) and that SEL is the basic building block of SARNAM, the small arms range noise assessment model. The disadvantages of SEL are that the operator needs time between shots to read and clear the SLM (because a typical military range is generating multiple and overlapping shots) and that the SEL is an unreliable measure when the level of the impulse is near the level of the ambient. When impulse and ambient levels are nearly the same, the operator will not be able to see the impulse register as a sudden jump in the meter reading. To avoid this difficulty, we in the U.S. tend to use the maximum A-fast or peak hold when the impulses are near the ambient level, though others methods may prevail in other countries.

When the operator uses A-fast and impulses are being generated at less than 1 every 5 seconds, the operator can usually pick out individual shots and write down the values on a notepad. The A-fast can then be converted to SEL by subtracting 8 dB. On the other hand, if the shots are faster than 1 every 5 seconds, the operator will have to keep a log of the level of activity for later comparison with the digital record of activity

Use of peak hold has the advantage of allowing the operator to immediately recognize the impulse responsible for the decibel reading registered on the sound level meter. When there is a volley of shots, peak hold will only register the highest level in the volley. Note: This feature would be a disadvantage if one is trying to characterize the average shot.

Measuring the LEQ from Small Arms Ranges

The preferred method for unattended monitoring of small arms fire is the A-weighted L_{eq} with the meter set to the fast time response. To allow for positive identification of the times of firing, a control monitor should be set up close to the firing line. This control monitor will allow the operator to separate the L_{eq} measured at the more distant sites of interest into ambient (no penalty) and gunfire (10 dB penalty required).   Increases in sound level at the more distant sites should correlate with increases in level at the control monitor. If this is not the case, then there is no way to know whether the distant monitor was measuring gun fire or background ambient.

6.4.3.4 CHECKING CONTOURS FROM LARGE WEAPONS

Sound levels from large weapons are among the most variable of military sources.   In fact, a study published by the Army Construction Engineering Research Laboratory (CERL) found that 50 to 150 days of sampling would be needed to validate a point on the BNOISE contour at Fort Bragg (Schomer *et al*., 1981), a task requiring unattended monitoring.

Unattended monitoring of the sounds of large guns is conducted with instruments that record noise only when the level exceeds a “threshold.” At a minimum, the instrument should record the CSEL, peak, and duration of each event above threshold (peak and duration are used to distinguish true gun sounds from artifacts). Table 6-1 gives an example of screening criteria. To reduce triggering by wind gusts, the threshold is usually set to 105 dBC and/or 110 dB linear peak but this threshold is above the level at which gun sounds are audible. Consequently, unattended monitoring misses events that would be picked up with attended monitoring.

Note: The screening criteria in Table 6-1 can be used with a number of commercially available, off-the-shelf sound measurement systems.

6.4.3.5 MONITORING FOR COMPLIANCE AND COMPLAINT MANAGEMENT

Depending on the situation, monitoring for compliance or complaint management may involve short term measurements with an observer, permanent, or semi-permanent monitors. For example, the U.S. Air Force has been required to conduct noise measurements to assess the impact of its flying mission. In 1984, as part of a Record of Decision to fly supersonic flights over Valentine, Texas and Reserve, New Mexico, the USAF had to conduct sonic boom monitoring that cost over $1.5 million. Validation studies have been conducted to increase confidence of the public in the noise models used for the Department of Defense AICUZ, RACUZ and ONMP programs. Among the situations falling under this category are the following:

Duration of the event less than 0.03 seconds or greater than 1 second
Total duration of the events during any minute exceeds 15 seconds
The difference between the C-weighted peak level and the SEL of the event is less than 15 dBC or greater than 25 dBC
The difference between the unweighted peak level and the SEL of the event is less than 20 dB or greater than 30 dB
The difference between the unweighted and C-weighted peak levels was less than 1 dB or greater than 10 dB

Table 6-1 Rejection Criteria for Screening Gun Noise

6.5.1 MONITORING THE NOISE EXPOSURE OF THREATENED AND ENDANGERED SPECIES

Several years ago the U.S. Air Force developed a noise monitor that could be put around the neck of an animal for studies to determine the effects of military overflights on wildlife. The U.S. Air Force has now started a new development program to consolidate all of its noise measurement requirements into a remote monitoring package. This package will use different sensors/storage for various measurements but the same RF transmitter hooked to a long haul communications system that transmits the data back to a remotely located computer system for analysis. This capability will allow the USAF to perform real-time monitoring of noise impact for determining its mitigation effectiveness.

When placement of monitors on a threatened or endangered animal species is not feasible, permanent monitors may be set up at their habitat. For instance, USACHPPM supported Joint Training Exercise Roving Sands At White Sands Missile Range by monitoring aircraft noise in the habitat of the desert bighorn sheep (*Ovis Canadensis mexicana*) (AEHA, 1992, 1994; CHPPM, 1997). These monitors were solar powered, thus allowing for extended monitoring in difficult-to-reach terrain.

6.5.2 SONIC BOOM MONITORING

The U.S. Air Force is required to monitor and describe sonic boom exposures in military operating areas (MOA) associated with air combat maneuvering instrumentation (ACMI) operations to assess the environmental impact of such operations. To satisfy NEPA, the Boom Event Analyzer Recorder (BEAR) (Lee *et al*., 1989) was developed to provide the U.S. Air Force with a readily portable, unmanned sonic boom recording system. The BEAR was designed to detect and record full sonic boom pressure-time signatures while rejecting unwanted noise events produced by subsonic aircraft, ground vehicles, gunfire, wind, and other sources. Thus, the recorder can discern a sonic boom from the normal background noise and store it digitally for later analysis.

The NASA Johnson Space Flight Center has also designed a remote sonic boom monitoring system that uses analog circuitry to collect sonic boom signatures (Norris *et al*., 1995). This NASA system utilizes a simple level-triggered detection algorithm and lacks the capability for long-term unmanned operation. From 1989 to the present, the BEARs have been used to monitor the sonic boom environment in the Barry Goldwater Air Force Range, White Sands Missile Range, and the Nellis Air Force Base Supersonic Range.

The BEARs have also been used in sonic boom research. In 1987, the units were used in the collection of reference sonic signatures that were later developed into the BOOMFILE database (Lee *et al*., 1991). In 1991, NATO used the BEARs to measure sonic booms during their joint acoustic propagation experiment conducted at White Sands Missile Range (Lee and Downing, 1991). Additionally, BEARs have been employed to measure sonic boom focus regions (Downing *et al*., 1997) and the sonic boom from a Titan IV rocket launch (Downing & Plotkin, 1996).
Above all, these field studies have shown that the BEARs are a valuable tool because they provide the U.S. Air Force with the required capability to

monitor sonic boom exposures in a cost-effective and accurate manner. The frequency range is sufficient to describe boom exposure generated by military aircraft, launch vehicles, and the NASA Space Shuttle. The units are compact and transportable for remote monitoring and provide an improvement in acquiring, storing, and retrieving sonic boom data in an immediate and accessible electronic digital file. And the boom data collected by these systems provide researchers with an additional source of data to improve our current knowledge of sonic booms.

6.5.3 MEASUREMENT OF LARGE SOUNDS WITH AN OBSERVER PRESENT

Not surprisingly, complaints about the sounds of large weapons are fairly common around Army and Marine ranges firing 120 mm tank cannon, 155 mm howitzers, or other large weapons. Air Force, Navy, and Marine bombing and demolition ranges also generate complaints and a common element in just about all complaints is concern about damage to the complainant’s house.

When measuring large weapons and explosions at the home of a complainant, measurements can be made with linear peak hold, C-weighted SEL, and C-slow (which give approximately the same reading as CSEL). The easiest setting to use is linear peak hold and then the CSEL can be estimated by subtracting 25 dB from the peak value.

A preferred method is to record the noise event with a high-fidelity recorder for detailed signal analysis. When the measurements are prompted by citizen complaints about guns rattling their homes, it may be useful to use a multi-channel recorder so that vibration measurements can also be recorded simultaneous with the sound. The vibration measurements can be evaluated to estimate the noise levels which could potentially result in damage to windows, crack plaster, or other structural items.

As mentioned before, a distinct advantage of attended measurements is positive identification of the source of the noise so artifacts, such as dogs barking and wind gusts, are screened out.

6.5.4 PERMANENT BLAST NOISE MONITORING SYSTEMS

The design of a permanent blast noise monitoring system presents different technical challenges than design of an aircraft noise monitoring system (such as NOISENET). The blast system must be able to register short impulsive events and discriminate gunfire from “false alarms” such as wind gusts, birdcalls, barking, and other transient sounds. Telephone or radio links are also needed to connect a network of monitors located in communities surrounding the installation.

The earliest design for permanent blast noise monitors reduced the number of “false alarms” by using information on the times that blasts arrived at a microphone. The design used two microphones, one close to the source and the other located in the community and when the close-in monitor registered a high level, the system opened a “gate” for a monitor located farther from the range. This method was pioneered by Darby *et al*. (1980) at a Navy bombing range near Maui, Hawaii. The delay time for opening the gate on Maui was the number of seconds sound took to propagate from the bombing range on the island of Kahoolave to Maui and the same technique, in a more recent version, is described by Snell and Wallis (1992). This works well for single events but the down side is that when weapons are firing at many locations, a simple gate is not effective.

A second generation of permanent blast noise monitors incorporates statistical criteria (such as that which is listed in Table 6-1) to discriminate true blasts from false alarms. With these monitors, when a sound fits the criteria for a blast, the decibel value pops up on a visual display at the Range Control Office. This feature is one of several options programmed into the firing information and range execution (FIRE) system software, a multi-purpose range administration and environmental management product that was developed by CERL (Schomer *et al*., 1988). This system has been installed at a few larger Army bases (such as Fort Drum, and Camp Graying) but has fallen out of favor and no longer in use do to **its expense, complexity and relative inflexibility**.

Using statistical criteria to distinguish true blasts from false alarms is definitely easier than using close-in monitors to gate information at farther monitors, but it is still not completely reliable. A study conducted at Aberdeen Proving Ground using “artificial intelligence” found that the best performance achievable with the kind of information contained in Table 6-1 was a “hit rate” of 0.908 with a false alarm rate of 0.256 (Dysart, 1996). The best performance comes when statistical criteria are used in conjunction with two sensors.

System designers have looked at three ways of combining two sensors to improve the detection of blast noise:

- Two Acoustic Sensors. When two microphones are separated vertically by one or two meters, wind arrives at the microphones at different times, and a blast arrives simultaneously. Thus, f the signals from the two microphones are summed, the wind cancels out and the blast remains as a strong signal. In a laboratory mockup, this configuration achieved a 97.5% hit rate with a 2.5% false alarm rate (Benson, 1996).

- One Acoustic Sensor with a Window Vibration Sensor. In the study at Aberdeen Proving Ground, Maryland, 99% discrimination rates were achieved by correlating the signal from a vibration sensor on a house windows with the acoustic signal from a microphone located a few feet from the house.

- Acoustic Sensor with Geophone. A third system, which has been installed at several Army installations, combines statistical criteria from the Air Force's BEAR (Lee *et al*., 1989) with an ultra-sensitive geophone. The geophone picks ups a small vibration from the airborne blast wave and uses this signal to gate the acoustic sensor. With this system, known as blast analysis and measurement (BLAM), near-perfect discrimination has been achieved with blasts above 105 dB Peak.

With the improved discriminability of two-sensor monitors, it is possible to reduce the threshold for analyzing a sound event from 105 dB linear peak to a lower decibel level. As the threshold is lowered, the likelihood of more than one monitor reporting a blast event increases, and it becomes possible to locate the source of a gun sound from information about when the sound arrived at a set of monitors. This sort of crude triangulation can provide a Range Control Officer with a rough approximation of the location of the gun from which high community noise levels are being generated.

The most sophisticated gunfire sound localization systems are those developed for battlefield use. These systems use arrays of four or more closely spaced microphones to get a bearing on a weapon. Then a special purpose computer program takes the bearings from three or more arrays to locate the weapon. But because these more sophisticated systems are more expensive to build and more expensive to maintain than the other systems described in this chapter, they have not been used for environmental sound monitoring at military installations.

6.6 MONITORING IN AREAS OF EXCEPTIONAL QUIET

During the 1990s, the U.S. National Park Service (NPS) and the U.S. Forest Service (USFS) adopted policies to preserve natural soundscapes in park and wilderness areas. Research carried out by the NPS is documented in a Report to Congress (NPS, 1995). In the future, the DOD may be faced with regulatory requirements to reduce noise levels and/or the audibility of training sounds in some areas with exceptional natural soundscapes. If such requirements do arise, the noise monitoring equipment would have to allow for low-level measurement of the sound.

One research team has suggested that the sound level exceeded 90% of the time would serve as a baseline for determining when the natural sound environment was being disturbed by intrusive, human-generated sound (Downing *et al*., 1999).

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CHAPTER SEVEN

REDUCING NOISE CONFLICT

As part of the DOD "good neighbor" policy, reducing the impact of noise for military families, living on the installation and everyone else living near the installation should be a goal of every base planner and range manager. Also, the National Environmental Policy Act (NEPA) requires that alternative actions to mitigate impact be considered in environmental analysis (Environmental Assessment, Environmental Impact Analysis Process, and Environmental Impact Statement). This chapter presents various noise control techniques that are available for mitigating the noise of military training and operations.

In keeping with the design of this manual, these techniques are presented under the following broad categories:

- Mitigation at the source
- Mitigation along the path
- Mitigation at the receiver

7.1 MITIGATION AT THE SOURCE

In the Noise Control Act of 1972, Congress exempted military materiel from mandatory noise control because some engineering controls could degrade performance in combat. Nevertheless, noise control at the source is considered in the design of new combat materiel. The driving forces are: (1) protecting the war fighter from hearing loss, (2) improving speech communication in combat, and (3) avoiding acoustic detection by the enemy. These considerations play out differently for fixed and rotary wing aircraft, tracked and wheeled vehicles, small and large weapons, demolitions, and generators.

7.1.1 QUIETING JET AIRCRAFT

Although civil aircraft have been beneficiaries over the years of mandated noise reduction by several Federal Aviation Administration regulatory actions, military aircraft have been exempt in order to maintain air superiority. Fighter aircraft may continue to get more powerful (and thus noisier) but there are efforts to require noise reduction for non-fighter aircraft.

7.1.1.1 GROUND RUN-UP NOISE

While on the ground, engine noise can be reduced with noise suppressors. These are generally either “portable” devices attached to the jet engine exhaust or “hush houses,” which are structures designed specifically to enclose the entire aircraft.

Since ground run-up noise is stationary, there are several opportunities for mitigation. The aircraft can be run in the aforementioned hush house, the engines can be trimmed out in test cells, or barriers can be erected to block the sound. Newer technologies, like the Portable Active Noise Reduction System, have been demonstrated to reduce the noise either globally or in a local area (U.S. Air Force, 1994, 1995).

When an aircraft is placed in a hush house or test cell, the muffling liners in the exhaust tubes absorb a large part of the acoustic energy. These systems do a great job of reducing the audible noise but there is a substantial amount of acoustic energy in the lower frequencies and, as shown in Figure 7-1, the hush house is less effective at attenuating these lower frequencies. Also, the inaudible low frequency acoustic energy, also known as infrasound, is not attenuated well by the atmosphere. So, under certain weather conditions, (i.e., a temperature inversion), infrasound can be trapped near the earth’s surface and propagate over several miles. This infrasound can induce natural resonance in buildings, causing a notable shaking and rattling of windows, furniture, etc.

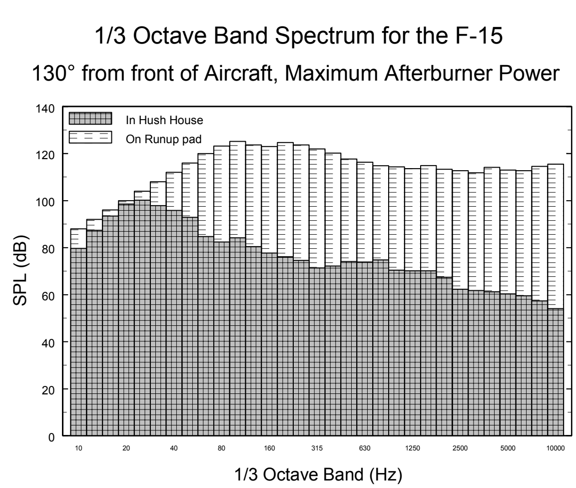

Figure 7-1 Comparison of Sound Energy on a Run-Up Pad and Hush House

Since the jet aircraft have a strong directivity pattern, orientation of the aircraft relative to the receiver location can make significant differences in the noise that is heard.

7.1.1.2 FLIGHT NOISE

During takeoffs and landings, the pilot has some options for reducing noise at the source. These include:

Reduced Thrust

Simply reducing thrust, or lowering the power setting, decreases noise. Reducing thrust at takeoff is the primary method of reducing sideline noise and is one of several methods of reducing climb-out noise. The potential benefits of this are offset, however, by the greater distances (and time) required to achieve a "noise free" altitude.

Full Throttle

The use of full throttle or full power throughout the takeoff will permit a maximum climb-out angle. More noise will be created near the runways but further down the flight track, noise will be reduced because of increased altitude.

Flap Setting

A steeper ascension angle and reduced thrust are possible if the flap angle is reduced after a prescribed velocity is attained. Both higher altitude and lower power setting will reduce noise impact. Reducing the flap setting reduces airframe drag, thus decreasing the amount of engine power required and increasing speed. The net result is decreased noise in outlying areas.

Delayed Flap and Landing Gear Extension

Delayed flap and landing gear extension will also reduce airframe drag, engine power required, and thus noise in outlying areas.

Power Cutback

A normal liftoff with a power reduction at a selected point down range will decrease near range noise and increase far range noise.

Afterburner Use Modification

Noise emissions during afterburner use are significantly higher than when the afterburner is not used. Cessation of afterburner use as soon as possible may result in lower exposure levels beneath the flight path but this reduction may be offset by the greater distances required to achieve a "noise free" altitude.

Regulation of Thrust Reversals

Some aircraft employ thrust reversals for added braking power when landing. Such reversals cause objectionable sideline noise near the runways. The restriction of thrust reversals is possible when runway lengths permit. Note: There is a tradeoff between reducing thrust reversals and increasing taxi time.

Sonic Boom Issues

Currently no method exists to minimize the source strength of the sonic boom generated by supersonic flights. Current research is exploring technologies that may be useful in the design of future aircraft to reduce the sonic boom but these technologies are currently only in the exploratory stage. One area where pilots can minimize sonic boom impacts is by understanding how flight maneuvers create focused sonic booms. With a basic understanding of focus boom generation, pilots can better avoid unintentional impacts from sonic booms. For instance, if a pilot is approaching a noise sensitive area at a supersonic speed, then the best approach to minimize the strength of the boom on the ground is to reduce speed and to perform a straight climb. The worst approach for a pilot in this situation is to perform a hard turn, which can generate an amplified focused sonic boom on the ground.

7.1.2 QUIETING PROPELLER AIRCRAFT

In concept, the techniques for jet aircraft apply to propeller driven aircraft but power cutbacks are not as effective because of lower engine noise levels. Because the propeller aircraft are generally quieter than jet aircraft, citizens complain far less about them and noise reduction is generally not needed. It should be mentioned that a propeller-driven aircraft for which source reduction will likely become a key focus of research is the Unmanned Aerial Vehicle (UAV) being used by the Army for battlefield surveillance, since low acoustic profiles on the battlefield contribute to success.

7.1.3 QUIETING ROTARY WING AIRCRAFT

Whereas fixed wing aircraft make more noise taking off than landing, helicopters make more noise landing than taking off. Current military helicopters are quieter than the models used during the Vietnam conflict – reductions that came primarily to lower their profile on the battlefield. The greatest decrease in noise level has been due to increasing the main rotor blades from two to four which then reduced the amount of "blade slap" or "blade vortex interaction (BVI)" noise. Research in the use of "smart materials" to further reduce noise from main rotor blades has been funded by the Army Research Office and may provide benefits in the future.

But two-bladed helicopters remain in use and guidance on noise reduction for these older helicopters can be found in the 1983 *Fly Neighborly Guide* published by the Helicopter Association International (HAI). The HAI Fly Neighborly Committee (composed of members of HAI, the FAA, military, and other associations) launched the Fly Neighborly Program in 1982 and their 1983 *Fly Neighborly Guide* (serving only as a guide not comprehensive) contained graphs showing combinations of air speed and approach angle that would result in high levels of BVI. Figure 7-2, reproduced from a NASA report (Chen *et al*., 1995), shows a comparable graph for the UH-60.

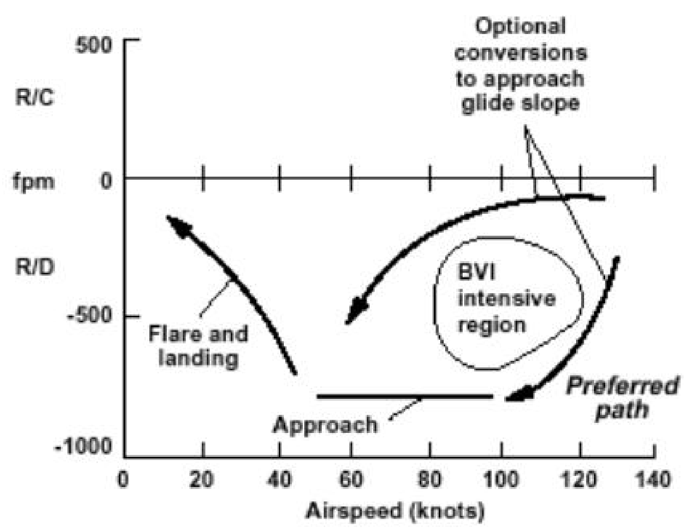

Figure 7-2 Preferred Flight Path to Avoid BVI Intensive Regions

A more recent publication by the HAI Fly Neighborly Committee is their 1993 pocket guide. This guide contains recommendations on noise abatement flight procedures for the following civilian and military helicopters:

- Aerospatiale AS350, AS355, AS365 and AS332
- Aerospatiale SA 365N
- Agusta A109A, A109A II, and A109C
- Bell (all models)
- Boeing 234 and CH-47
- Enstrom F28F and 280FX
- MBB BK117 and BO105
- McDonnel Douglas (Hughes) MD500N, MD500D and MD500E
- Robinson R22
- Rogerson Hiller UH12 and RH1100
- Schweizer 300C
- Sikorsky S-76A
- Westland 30

7.1.4 QUIETING TRACKED VEHICLES

The acoustic signature of the U.S. main battle tank, the M1E1A, is much lower than older main battle tanks such as the Korean War-era M-48 and the Vietnam War-era M-60. The primary reasons for the reduced signature are the use of a turbine rather than piston engine and innovations in the design of the vehicle tracks.

Track noise has been reduced by a combination of nitrile rubber pads and an actively controlled track tension system. In addition to reducing track noise, nitrile rubber increases track pad life from 1000 to 3,000 miles and increases fuel economy and track bushing life (U.S. Army, 1998).

7.1.5 QUIETING WHEELED VEHICLES

In the 1970's, the Army learned a lesson about the importance of noise control when, while developing a wheeled vehicle known as the GOAT hearing conservation specialists discovered that the prototype generated hearing-hazardous noise levels at the driver's position. Since that time, driver-position sound levels are evaluated on all vehicles and battlefield detectability is also taken into consideration. Sound classification criteria are found in MIL Standard 1474.

7.1.6 QUIETING GENERATORS

Historically, generators have been more of an environmental noise problem for deployed troops than a community noise problem. Soldiers routinely built barriers out of sand bags to shield their tents from battlefield generator noise; whereas the only identified community noise problem from generators was at Fort Belvoir, Virginia (where the complainants were located across water from the generator test center).

Thankfully, in the late 1990's, new Tactical Quiet Generators were introduced as replacements for the old styles and now soldiers can actually stand near a running generator and hold a conversation. Fittingly, the first units to receive the new generators were combat units.

7.1.7 QUIETING EXPLOSIVE CHARGES

As weapons become obsolete or the shelf life of ammunition is exceeded, the operators of Army ammunition plants and depots must dispose of the old ammunition. Smaller caliber ammunition can be destroyed in "popping furnaces" but larger ammunition must be blown up at a demolition ground. The traditional method for reducing demolition ground noise is burial.

7.1.8 QUIETING SMALL ARMS

A number of devices for quieting the noise of small arms were described in a November 1985 reported prepared for the German Federal Environmental Office by the Institute for Noise Protection in Duesseldorf (Buchta, 1985). German researchers found that they could reduce the muzzle blast of a 7.62 mm rifle by 15 to 20 dBA using a silencer with a 50 mm cross section, 185 mm length, and 710 gram weight. However, this device precluded realistic combat training so its use fell out of favor. Another innovation is the silencer box. Silencer boxes are large boxes or tubes wherein the barrel or the entire gun is then placed and shots are fired through the open ends of the apparatus. They allow for relatively free movement of a weapon (although target angles are limited by the length of the tube) without the need for modifying the weapon itself. Firing through a silencer box eliminated the additional weight at a mounted silencer would add to a gun while achieving 15 to 18 dB noise reductions. Specifications for a low-cost U.S. version of a silencer box have been developed by the Construction Engineering Research Laboratory (CERL) (Pater and Krempin, 1997) and it can be assembled rather inexpensively from 22-inch diameter corrugated plastic drainage pipe and with a duct liner for about $125. Prototypes at Camp Dodge, Iowa, demonstrate a noise level reduction of about 15 dB.

7.1.9 QUIETING MEDIUM CALIBER GUNS

In response to legal action taken by German citizens living near an Infantry Fighting Vehicle range at Wildflecken Training Area; engineers at the Army Ballistics Research Laboratories designed and tested a muffler for the 25 mm gun in 1986. Although the device was effective in reducing noise, the weight caused the gun tube to bend and there were problems with clearance of gasses from the vehicle. These problems were solved, but with the "draw down" of combat units in Germany, range usage dropped dramatically, and the device was no longer needed.

7.1.10 QUIETING LARGE CALIBUR GUNS

Large caliber weapons generate three distinct sources of noise: the propellant blast, the sonic boom from supersonic projectiles, and noise from target impact. Source reduction can be achieved for the propellant blast and noise from target impact, but not the sonic boom.

The earliest work on silencing a large weapon was conducted in 1969 at Rock Island Arsenal, Illinois. The weapon was the M102, 105 mm howitzer and the multi-chambered silencer was 20 feet long and 5 feet in diameter. The silencer worked to a degree but when this device was tested with the more powerful M68, 105 mm tank cannon, the suppresser eventually succumbed to an internal structural failure in which the first baffle suffered a severe “dishing” (apparently caused by the impulsive force of the initial shock wave).

Building on this initial failure, an engineer at the Benet Weapons Laboratory, Watervliet Arsenal, New York used a water table to model the “uncorking” of the propellant blast. The improved Benet model confined the initial blast to a small, very strong chamber which formed a high-pressure, pre-suppresser. In 1975, this new design was successfully tested with a 20 mm silencer having a diameter of 11.5 inches and length of 33 inches. Then, in 1983, Avco developed an alternative design for 105 mm tank gun testing at Camp Edwards, Massachusetts. The AVCO muffler, with a diameter of 7.5 feet and length of 20 feet, achieved a 15-20 dB reduction (AEHA, 1985). Eventually, this muffler was moved to Aberdeen Proving Ground, Maryland, when the Avco operation at Camp Edwards closed.

A limitation on all of the mufflers for large guns is the massive weight required. In its original configuration, the Avco muffler had to be embedded in an earth berm to prevent the metal from “ringing” with each shot. It was soon discovered that another way to improve the effectiveness of a muffler is to fire through foam. A report published in 1981 by engineers at the Naval Surface Weapons Center, Dahlgren, Virginia demonstrated that the peak sound pressure level of a 7.62 mm rifle blast was reduced by 10 dB or more if fired through a canister of aqueous foam (Pater and Shea, 1981). In the late 1980’s, engineers from CERL tested the foam concept with larger weapons at Aberdeen Proving Ground and, although the idea worked, the logistics of filling a canister with foam have discouraged range operators from using the technique.

Mitigation of noise from firing large caliber weapons can only be used at proving grounds and repair facilities since the use of mufflers would preclude realistic training. Mitigation of noise at the target or impact area is compatible with realistic training if adequate training can be achieved with a training round.

For artillery training, where the targets are scrapped vehicles towed into the artillery impact area, most training is conducted with high explosive (HE) rounds. But, if noise reduction is required, a training round is available. By substituting the M804 practice round for the M107 HE round, the primary source of noise from 155mm artillery training can be eliminated. Also known as the LITR, the M804 round contains a small smoke canister in the fuse well which provides the visual signal needed by the forward observer to direct artillery fire. It can be used in training at less cost than an HE round and without the blast and fragmentation. Beginning in 1982, the military attempted to use this round at Camp Edwards, Massachusetts in an effort to reduce complaints from residents of Cape Cod. While the training round was quieter, it was not enough and the noise complaints continued resulting in the elimination of all artillery training from Camp Edwards.

Another important training round is available for the Multi-Launch Rocket System (MLRS), a devastatingly powerful weapon with a range exceeding all the Army installations except Fort Bliss and Yakima Firing Center. This training round has a concave front to slow the rocket and there is no explosion at target making for a relatively low acoustic signature (USACHPPM, 2000). Development of the MLRS training round allowed for the introduction of MLRS training at smaller facilities such as Camp Shelby, MS.

7.2 MITIGATION BY ALTERING THE PATH BETWEEN SOURCE AND RECEIVER

Military planners have few opportunities to mitigate military noise at the source but they have a lot of opportunities to mitigate by altering the path between source and receiver. There are six main ways to do this:

- Increase distance
- Take advantage of ground impedance
- Employ a vegetative barrier
- Use a barrier, berm or natural terrain
- Change source direction
- Optimize meteorological conditions

7.2.1 INCREASING DISTANCE

The simplest way to reduce noise levels is to lengthen the distance between source and receiver. An acoustical rule-of-thumb is that sound pressure level decreases by 6 dB for every doubling of distance from a *point source* (such as a generator). Thus, increasing the distance from 200 feet to 300 feet does not provide as much reduction as moving from 100 to 200 feet. In practice, high frequency sound is attenuated faster than 6 dB per doubling because some energy is lost to the air and this additional loss is called *excess attenuation*.

Another exception to the 6 dB per doubling rule is when referring to a *line source* (such as a busy freeway) rather than a *point source*. When standing to the side of a line source the listener receives noise simultaneously from the entire breadth of the feature; in this case, it would be the line of cars traveling on the freeway. For the ideal line source, sound pressure level drops by 3 dB for every doubling of distance from source. In practice though, highway noise tends to drop off by about 4 dB for every doubling of distance from the highway.

Altering the distance between military fixed wing aircraft and the receiver can be used in conjunction with the source modifications discussed in Paragraph 7.1.1 but both are operational modifications so the opportunity to employ them may be limited. And since the goal of the air installation planner is to create an environment that will support aircraft operations, extensive operational modifications will normally be unacceptable. However, such alternatives should not be ignored as possible methods of reducing noise conflict and the following options may be useful:

- **Increase Holding and Maneuvering Altitudes.** Sufficiently high holding and maneuvering altitudes can reduce noise around airfield.

- **Increase Approach Glide Angle.** By increasing the approach glide angle to the maximum practicable, noise can be reduced (but to a constantly diminishing degree) in areas under runway approach. Noise reduction is due to increased altitudes and engine power.

- **Utilizing High Speed Approach.** A high-speed approach can reduce noise in outlying areas. Aircraft descent is at a high speed with reduced thrust, utilizing aerodynamic drag and flap and landing gear adjustments to control speed. The procedure adds to pilot workload and is best suited for aircraft equipped with automatic landing system.

- **Altering Takeoff Procedures.** Associated with takeoffs are two types of noise: *sideline* and *climb-out*. Sideline noise is characterized by engine noise and the effects of noise reflection caused by structures near runways; it occurs when an aircraft is on or close to the ground. Climb-out noise is also dominated by engine noise and occurs when an aircraft is above building height. Controlled aircraft thrust is paramount in abating both types of noise. Most of the takeoff procedures discussed in Paragraph 7.1.1 will result in decreased noise in one area and increased noise in another. This tradeoff must be weighed against the patterns of sensitive and non-sensitive land uses to minimize detrimental noise impacts. Again, maintenance of the flying mission and safety must take precedence.

Another option to reduce the possibility of noise impacts is to change the training flight tracks. The location of flight corridors or routes, especially near runways when aircraft are closer to the ground, is a controlling factor in noise emissions. By dispersing corridors, the amount of area subject to noise and crash potential will increase but the severity of the noise impact will diminish. Conversely, flight paths can be concentrated into a single corridor, thus decreasing the amount of land affected while increasing the severity of impact.

On paper, changing flight tracks is easier for rotary wing than fixed wing operations but many installations have “no fly” zones for helicopters, especially near ratite ranches and horse farms. Also, the choices available to helicopter pilots are frequently limited by FAA requirements to stay below a minimum altitude in areas with commercial air traffic, such as at MAS Miramar in San Diego.

There are several practical constraints limiting the relocation of flight tracks. First, the complexity of flight tracks near typical airbases may require that several flight tracks be relocated to completely avoid overflight of certain areas, often at the expense of more flights over other areas. Second, current approach, departure, and closed-loop pattern flight tracks blend into the local and regional Air Traffic Control (ATC) system so any proposed changes must be carefully checked and reviewed by ATC. Finally, any change in flight track routing must not conflict with the airbase mission. In spite of these difficulties, careful planning of flight track locations can reduce aircraft noise exposure, particularly when new aircraft and/or missions are assigned to the airbase.

This approach can be varied to handle problems in a particular area or during a specified time. Flights can be concentrated into a route that avoids noise sensitive areas and corridors can be changed according to the time of day so that night flights are routed over areas not used during the night. Similarly, changes can be made seasonally to reduce the effects on facilities which may be used only during certain times of the year.

When dispersing corridors, planners should ensure that there will not be a significant increase in the DNL in other noise sensitive areas *even if the DNL remains below 65 dB*. For example, when corridor dispersion from the three metropolitan New York-New Jersey airports was increased in 1987 under the Expanded East Coast Plan (EECP), the DNL in rural communities increased from the low 40’s to the high 40’s. In the most effected community, the DNL increased from 42 to 49 dB and six percent of the citizens filed formal complaints (Muldoon and Miller, 1989).   Even though the EECP did not change the location of the 65 dB contours, the political furor from people living in previously quiet areas forced the FAA to revisit their decision through a formal (and expensive) environmental impact statement (EIS).

Aircraft noise exposure can be distributed (evenly or in other ways) in the area around an airbase by controlling runway usage. Prevailing winds dictate runway usage at an airbase when winds are over 5 knots. At lower wind speeds, cross wind and tail wind takeoffs and landings are allowed, but usually the “main direction” is maintained. At airbases with single or parallel runways, one direction may be used for 80% or more of total aircraft operations and this may be desirable if residential usage is in the direction away from the takeoff pattern. Alternatively, if noise-sensitive areas are equally distributed around the airbase, noise exposure could also be more evenly distributed by instituting a preferential runway usage policy.

For military training routes (MTRs), noise mitigation can be achieved by changing where the missions are flown. Missions can be moved to an entirely new MTR where the impact is less because of smaller, fewer, or more distant receiver locations or existing MTRs can be fully or partially modified. Users should recognize that creating a new MTR or moving some segments of an MTR involves several considerations, many of which are not noise related.

For supersonic operations, changing the location of the flights is limited by the size of the military operations area (MOA) or range and the local topography. Use of mountains and valleys is often part of the training exercise and cannot be moved. Also, the propagation of a sonic boom is not intuitively obvious so use of PCBOOM is an essential tool in planning mitigation in the vicinity of a sonic boom corridor. The PCBOOM program (described in Chapter 5) models sonic booms from individual operations and MOABOOM is used to predict a total boom exposure from multiple operations.

To mitigate sonic booms, the primary method has been to simply avoid sensitive locations and this has logically resulted in most supersonic operating areas being located in remote areas. Theoretical studies on aircraft design can change the shape of the N-wave (which lessens the impact of the sonic boom) but weather conditions and normal propagation over distances greater than 3,000–4,000 feet eliminate this rounding effect.

7.2.2 TAKING ADVANTAGE OF GROUND IMPEDANCE

When a sound wave propagates along the surface of the earth, acoustic energy can be lost in several ways. One of those is directly into the ground. When sound propagates over a freshly plowed field or loose snow, it is attenuated much faster than when it propagates over a lake or an expanse of flat concrete. So when locating a helipad, for instance, it would be better to have grass between the pad and the community than to have asphalt. Similarly, when laying out small arms ranges, it is preferable to locate ranges where soldiers fire from a prone position closer to the community and ranges where the gun is fired at a higher position (e.g., pistol or sniper range) farther from the community. Ground impedance is particularly useful with rifles because rifles tend to generate most of the sound at 500 Hz and ground is particularly good at attenuating at 500 Hz. With a large 25 mm gun, though, taking advantage of ground impedance through defilade fire from a depression in the ground does not appear to be effective in reducing noise levels (Raspet, 1986).

The converse of taking advantage of ground impedance is to avoid having bodies of water between military training and the community. Obviously, coastal installations such as Aberdeen Proving Ground, Maryland have little choice but to fly over water. Nevertheless, planners at installations bordering on recreational lakes should be aware of how well sound can travel over a lake or pond.

7.2.3 USING VEGETATION

Just as the war fighter can use vegetation to reduce his acoustic signature in combat, the installation planner can use vegetation to reduce training noise in the community. In a type of training known as Nap of the Earth (NOE) flying, helicopter pilots take advantage of both terrain and vegetation to reduce the distance at which ground troops can detect their approach.

Forests are more effective in reducing high frequency sound than low frequency sound. A rule of thumb is that the attenuation from each meter of forest is equal to 0.01 dB times the cube root of the frequency. For example, the cube root of 1000 Hz is 10 (i.e., 1000 = 10 x 10 x 10), and a

1000 Hz signal would be expected to lose 0.1 dB for each meter of forest. In contrast, the cube root of 27 Hz is 3, and this low frequency would be expected to lose 0.03 dB for each meter of forest. This equation shows that forest is much more effective in reducing the annoyance of things like small arms than the annoyance of large weapons. Not only is the forest relatively ineffective in reducing the "house rattling," low frequency components, but the low frequencies are more likely to propagate over the tops of the trees. For these lower frequencies, the effectiveness of the forest depends on the amount of litter on the forest floor. The level of low frequency noise is reduced as the litter layer thickens and additional attenuation may be achieved by adding small earthen berms that serve both to contain litter and as platforms for bushes and undergrowth. The undergrowth, in turn, fills the space between tree trunks with leaves for additional noise attenuation.

For traffic noise, landscaping, although aesthetically pleasing, is not highly effective in abating noise unless it is dense, thick, and tall. If vegetation is not dense enough to obscure the sight of the noise source, its acoustic effect will be inconsequential. A reduction of 5 dB for every 100 feet of dense landscaping at least 15 feet high is appropriate and maximum degree of reduction than can usually be expected is 10 dB. Nevertheless, it is common for homeowners to ask for such screening as a means of noise control and there is some research showing that the visual screening reduces noise annoyance. The reasons for such reduction in annoyance are discussed in Section 7.3.

Moreover, traffic noise barriers also reduce glare, dust, and fumes. To avoid the adverse effects of barriers, design considerations should include maintenance, noise reflection, shadow effects, drifting sand or snow, and other related factors.

7.2.4 USING A BARRIER, BERM, OR NATURAL TERRAIN

The most common use of sound barriers is to shield homes from highway traffic noise. When the LEQ from traffic noise during the busiest hour of the day exceeds 70 dB at a residential property, the Federal Highway Administration has regulatory authority to fund a traffic noise barrier. This rule applies to military housing to the same degree as it applies to private homes and several installations have obtained traffic noise barriers to protect military families from undue disturbance.

Most acoustical engineers calculate the effectiveness of barriers using a mathematical equation developed by Maekawa (1968) and this equation accurately predicts the performance of barriers under most conditions. Nevertheless, it is good engineering practice to make noise measurements before and after construction of a barrier to confirm its effectiveness. Installation planners considering construction of a barrier, berm or barrier/berm combination are advised to consult an acoustical engineer for the design. Also, user-friendly software packages for designing sound barriers are available and in use by DOD environmental noise experts. For small arms ranges, the efficiency of different barrier designs can be evaluated using SARNAM.

Barriers, which are most effective against higher frequency sounds, must be located in the line-of-sight between the source and the receiver. Barrier effectiveness increases with height, width, and proximity to either the source or the receiver but if there are gaps in a barrier, the potential benefits of acoustical shielding will be substantially reduced. Furthermore, the effects of all barriers are lessened by atmospheric sound scattering and by the effects of noise "spilling" around the edges of the barrier. Besides acoustic advantages, barriers also visually obscure the noise source and thus further benefit the noise recipient psychologically.

There are many ways to build a barrier and many types of construction material may be used and acoustical engineers have access to a large body of literature to assist in barrier design. Usually, barriers are used with continuous noise sources but they can be used with weapons as well. The following brief discussion of traffic noise barrier performance (Figure 7-3), applies to barriers for weapons noise as well. This discussion has been reproduced in part from the Federal Highway Administration's website.

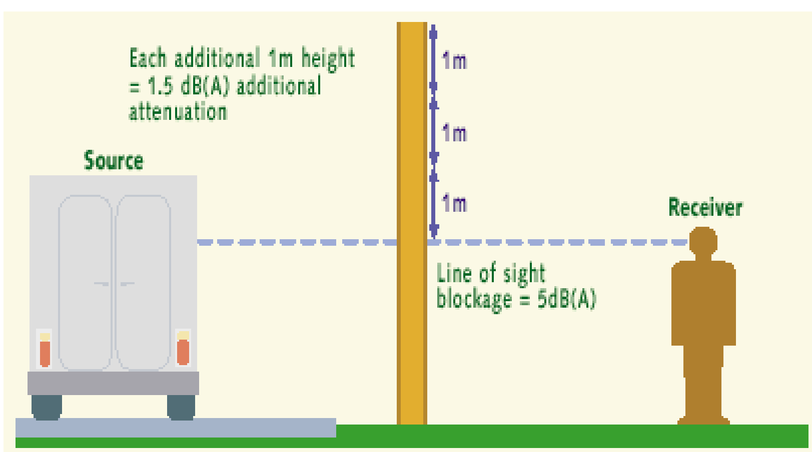

Figure 7-3 Explanation of Traffic Noise Barrier Performance (provided by the Federal Highway Administration)

Noise barriers reduce the sound which enters a community from a busy highway by absorbing the sound, transmitting it, reflecting it back across the highway, or forcing it to take a longer path over and around the barrier. A noise barrier must be tall enough and long enough to block the view of a highway from the area that is to be protected, the "receiver." Noise barriers provide very little benefit for homes on a hillside overlooking a highway or for buildings which rise above the barrier. A noise barrier can achieve a 5 dB noise level reduction, when it is tall enough to break the line-of-sight from the highway to the home or receiver. After it breaks the line-of-sight, it can achieve approximately 1.5dB of additional noise level reduction for each meter of barrier height.

When evaluating the performance of barriers, acoustical engineers look at the *path length difference*. This concept is illustrated in diagram Figure 7-4 by three lines:

- Line X – from the noise source to the top of the barrier
- Line Y – from the top of the barrier to the receiver
- Line Z – from the source to the receiver

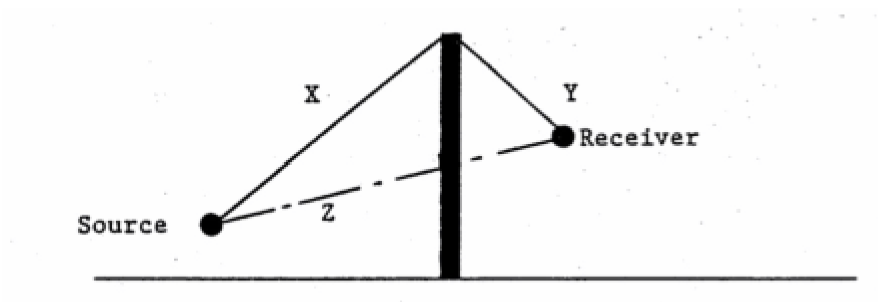

Figure 7-4 Concept of Path-Length Difference for Evaluating the Performance of Barriers

Path-length difference is determined by the difference between Line Z and the sum of Lines X and Y. The greater the path length difference, the better the performance of the barrier. Conversely, the effectiveness of a barrier is degraded by the following:

- **<u>Increases in Distance between Source and Receiver</u>**. As the source and/or receiver are farther from the barrier, the size of the path length difference decreases, and the barrier performance degrades.
- **<u>Increases in Receiver Height</u>.** If the receiver is in a multi-story building and the most noise sensitive activities take place in the

upper floor(s), it is a waste of money to build a barrier to protect only the first floor.

- **Increases in Source Height.** With road traffic, the source is tire noise at the road surface and engine noise less than a meter above the road surface; with jet engines, the source is several meters above the tarmac. To be equally effective, the barrier for the jet engine must be higher than the barrier for road traffic because of the difference in the source heights.

- **Shortening the Length of Barrier.** An effective barrier for a line source must be longer than for a point source. For line sources, the full attenuation will be realized only if the barrier is sufficiently long to cover an angle of observation greater than 160 degrees.

Special Considerations for Gun Noise

Path length difference is only one of the variables considered in the mathematical equation to predict noise barrier performance. The other variable is the frequency of the sound. Low frequency sounds require higher barriers than high frequency sound. This consideration is important when considering the use of barriers for mitigating the sounds of guns. As the caliber of a gun tube increases, the acoustic spectrum of the propellant blast shifts toward lower frequencies and the efficiency of a typical barrier decreases. For a rifle, which has a spectrum centered around 500 Hz, effective shielding can be achieved with ordinary traffic noise barriers because traffic noise also has a spectrum centered around 500 Hz. But traffic noise barriers (and barriers in general) will not work with the largest guns because a tank main gun, for example, would require a 200-meter high barrier to achieve the same decibel reduction as a 4-meter high barrier provides for a rifle.

Special Considerations for Aircraft Noise

Barriers are not utilized extensively to abate aircraft noise but they can be effective when aircraft are operating on or near the ground. Properly positioned barriers may reduce the sideline noise of fixed-wing aircraft that is generated during taxing, takeoff, landing thrust reversal but the effectiveness is not well established due to limited application. During takeoff, the maximum effects of a barrier will occur when an aircraft is still on the ground and approximately 45° beyond the point being shielded (the 45° is measured from an axis drawn through the shielded point and perpendicular to the flight track). For landing aircraft, barriers will reduce sideline noise to the front and rear after touchdown.

Buildings along runways afford partial shielding and landscaped earth berms are the least expensive and can be the most aesthetic barrier option. In fact, field measurements at the Minneapolis-St Paul Airport barrier (a one mile long, 15 foot high earth berm with 25 foot trees planed 60 to 100 feet deep) affirm a 5 dB minimum reduction in selected areas. It must be noted, though, that barrier with a smooth solid surface may actually reflect noise into regions beyond the barrier, making matters worse. This effect can be mitigated with the use of a surface treatment or vegetation that has absorptive and/or dispersive properties.

Barriers offer little relief from rotary wing operations because of the rapid vertical ascent capabilities of the aircraft. However, buildings interposed between the helipads and the community can act as barriers.

Special Considerations for Motor Vehicle and Railroad Noise

Noise barriers are capable of reducing the noise of railway, street, and combat vehicles in areas around fixed guide-ways or paths. Where combat vehicles are executing field maneuvers, the use of barriers for abatement is less feasible. In this case, barriers should be erected as close as possible to the noise receiver, not the noise source.

Several types of barriers have been used extensively along highways with the most common being earthen berms and wooden, block, and concrete walls. These obstructions approach a maximum effectiveness of 22 dB. Rows of buildings will also provide noise attenuation if the source is completely shielded by the structures, both vertically and horizontally. A single row of structures with less than 20% open area between structures will provide 5 dB of attenuation. Succeeding rows will provide an additional 2 to 3 dB each, up to a maximum attenuation of 10 dB for all rows. Natural terrain and roadway configuration also can help reduce noise.

7.2.5 CHANGING THE DIRECTION OF THE SOURCE

Many military noise sources make more noise in one direction than in another. An unmuzzled gun tube generates 12 to 14 dB more noise in front than in back, whereas a gun tube with a muzzle (such as a M198 155 mm howitzer) has a more uniform directivity. Jet engine run-ups are also highly directive; noise levels in front of the aircraft are substantially lower than at points the same distance toward the aft end of the aircraft. Helicopters also have a pronounced directivity with higher noise levels in the direction of main rotor blade rotation.

A number of operations usually contribute to the noise at any given receiver location. To fully explore the advantages of changing the directivity or location of specific sources, one needs to know the top contributors to the noise at the receiver location. Some of the models described in Chapter 5 have an ability to rank the operations with the greatest noise. In fact, the specific point receiver analysis output generated by the NOISEMAP computer program is used for this purpose, relying on the Total Noise Exposure (DNL contribution) to create the rank ordering. It should be noted that this can sometimes be misleading since the single event levels can create an impact on a few close-by residents. Here, the "good neighbor" policy would suggest that if significant noise reduction can be made to reduce the burden on the nearest neighbors, it should be done.

In SARNAM and BNOISE2, the user has the option to look at peak levels from individual weapons. Firing points that consistently generate levels at residential properties exceeding 115 dB linear peak should be moved or realigned.

7.2.6 OPTIMIZING METEOROLOGICAL CONDITIONS

Weather has a large effect on the propagation of sound. In some situations, it may be possible to schedule a particularly noisy activity at a time when meteorological conditions are unfavorable for propagation of sound in the direction of noise-sensitive receivers. In other situations, it may be possible to take prevailing weather conditions into account when choosing a site for a particularly noisy activity.

As a general rule, sound levels are higher at a given distance downwind than at the same distance upwind. For this reason, it is better to locate a range or engine test stand downwind from a noise-sensitive area than upwind. Beyond 5 kilometers, a surface wind in one direction may be overlain at a higher altitude by a wind in the opposite direction. Depending on the exact configuration (and the presence/absence of a temperature inversion), it is possible for sound levels to be greater upwind of a surface wind.

The effects of the weather on the propagation of battlefield sounds have been known since at least the U.S. Civil War where anomalies in sound propagation had documented effects on the outcome of important battles. But the technology to predict propagation was not available until World War II. In the 1950's, scientists at Sandia Laboratory began using meteorological data to avoid worst-case conditions in communities located near atomic bomb testing.

When predicting how much noise a community will receive from artillery training, weather is a more important variable than the size of the weapon. Although the 15 lbs of high explosive (HE) in a 155 mm howitzer round will, on average, make more noise than the 5 lbs of HE in the 105 mm round; a 105 mm howitzer round under worst case weather conditions will sound louder than a 155 mm round during ordinary conditions. The study of the propagation of 5 lb charges used to develop the original database for BNOISE showed a range of 40 dB at 2 miles from the detonation site at Fort Leonard Wood, Missouri.

The earliest U.S. Army effort to predict worst-case blast propagation was carried out in the late 1950's and early 1960's when the Explosives Research Group (ERG) from the University of Utah conducted studies at all of the Quartermaster Corps demolition grounds. Using strain gauges to measure the blasts and weather balloons to measure meteorology, the ERG derived a set of guidelines for "good" and "bad" firing conditions. These are reproduced in Table 7-1.

These guidelines are more useful in telling the range operator that there will be a worst-case condition than in showing where the worst-case condition will occur. Worst case conditions occur as a result of blast noise "focusing" which is caused by a channeling of blast noise through the warm air layer of a temperature inversion, a specific wind gradient, or a combination of inversion with a wind gradient. As a rule, when blast noise is focused in one location, its level decreases in other locations. The area of decreased sound level is known as the "shadow zone."

The blast prediction computer programs described in Chapter 5 can be used to determine the focus and shadow zones. However, it is important to remember that focus and shadow zones are dynamic, particularly at night. Any particular analysis only represents a "snap shot" of noise propagation during a particular set of meteorological conditions. Still, this snap shot can provide a good estimate of the direction in which a focus will occur.

Ordinarily, the users of blast prediction software are the operators of research and development and testing installations, since the soldier does not have the luxury of scheduling training around the weather. Nevertheless, there are some situations in which a training activity might be changed to avoid worst-case conditions and impacting training. Examples include the substitution of 500 lb bombs for scheduled 2000 lb bombs, the substitution of inert artillery training rounds for HE rounds, use of proximity detecting (PD) fuses on artillery rounds (which detonate the rounds at ground level) instead of Variable Time (VT) fuses (which detonate the rounds in the air above the target), and the delay of large open air explosions such as Mine Clearing Linear Device (MICLIC).

“Good” Conditions	“Bad” Conditions
CLEAR SKIES WITH BILLOWY CLOUD FORMATIONS, ESPECIALLY DURING WARM PERIODS OF THE YEAR A RISING BAROMETER IMMEDIATELY FOLLOWING A STORM	DAYS OF STEADY WINDS OF 5-10 MPH WITH GUSTS OF GREATER VELOCITIES (ABOVE 20 MPH) IN THE DIRECTION OF RESIDENCES CLOSE BY. CLEAR DAYS ON WHICH “LAYERING” OF SMOKE OR FOG ARE OBSERVED. COLD HAZY OR FOGGY MORNINGS. DAYS FOLLOWING A DAY WHEN LARGE EXTREMES OF TEMPERATURE (ABOUT 68 DEGREES F) BETWEEN DAY AND NIGHT ARE NOTED. GENERALLY HIGH BAROMETER READINGS WITH LOW TEMPERATURES

Table 7-1 University of Utah Criteria for “Good” and “Bad” Firing Conditions

7.2.7 ACTIVE NOISE CONTROL

A new and expensive technology, called Active Noise Control (ANC) or Active Noise Reduction (ANR), is starting to be applied to aircraft noise. This technology uses computerized control strategies to actively reduce noise emitted from aircraft. ANC is primarily used for low frequency noise as a complement to the passive noise reduction methods that commonly work well for high frequency noise. ANC systems attempt to measure the noise as it being generated and then produce a counter noise (or anti-noise) that destructively interferes with and cancels the propagating source sound. These systems can be designed for either global or localized reductions of noise. One limit of a global system is that the generated anti-noise must be of the same magnitude as the noise source itself resulting in limited application to jet noise. Noise generation technology will have to increase significantly before such large-scale systems are feasible. On the other hand, localized ANC systems are not limited by this restriction since the anti-noise source can be placed away from the noise source. Localized systems have been designed for jet run-up noise as well as aircraft departures (Sharp *et al*., 2001). One characteristic of the localized control design is that the overall noise levels will be reduced within the controlled area, but may be increased outside this area.

7.3 MITIGATION AT THE RECEIVER

In most textbooks on environmental noise control, mitigation at the receiver refers to some action to decrease the annoyance experienced by people. But the DOD is also the guardian of a large number of threatened or endangered species (TES), and reducing their reaction to noise is also important.

In regards to people, the military planner must consider two populations: military families living on the installation and residents living near the installation. For the first population, the planner can take a direct and active role. In contrast, for the second population, the planner’s role is indirect. Serving as the commander’s “noise expert,” the planner may be invited to provide information to local planning and zoning boards or even serve as ex officio members on planning boards. At the other extreme, some local governments have flatly rejected cooperation with the military in planning mitigation at the receiver. Either way, the planner’s relevance to the mitigation of noise off the installation is dependent upon the actions and attitudes of the surrounding local governments. This is why it is critically important for an Installation to facilitate positive relationships.

Among the methods available to mitigate noise at the human receiver are scheduling, acoustic design, land use planning, and public education.

7.3.1 SCHEDULING

Planners and operators at some installations have flexibility in scheduling ranges or operations and some forethought into scheduling can provide major gains in complaint reduction.

Flexibility in scheduling can be used to avoid disturbing people when they are most likely to be annoyed. For instance, it may be of great benefit to delay weekend Guard or Reserve training during services in a nearby church. In other countries, operations may be curtailed on special days, such as at MCAS Futenma on the Okinawan “memorial day” when families visit ancestral graves located off the main runway. Not knowing about local holidays can damage community relations. At Wildflecken Training Area in Germany, the beginning of a highly politicized controversy over an Infantry Fighting Vehicle range came about through the unannounced inauguration of firing on an important religious holiday (Pentecost).

Moreover, although night operations are absolutely essential to military readiness, unnecessary scheduling at night should be avoided. This form of mitigation is “built into” the noise methodology developed by the United State Environmental Protection Agency (EPA) in 1974. When using DNL, one must give a 10 dB penalty to sounds made after 2200 and before 0700. This penalty equates to treating each nighttime sound as if it were equivalent to 10 daytime sounds at the same loudness.

If there are night operations, it is important for people to know when the operations will end. This is especially true when the sounds occur sporadically, such as during artillery training.   Many complainants trace their irritation to the scenario where they are lying in bed, just beginning to fall asleep, and then are awakened by another unexpected explosion when they thought the training had stopped.

At airfields, a steady flow of traffic that minimizes waiting time to take off or land can reduce noise at and around the air base. If a school must be over-flown, it is preferable to schedule takeoffs before classes begin in the morning or end in the evening. Additionally, changes in aircraft ground run-up scheduling can provide significant noise mitigation by reducing or eliminating operations between 2200 and 0700.

Under the rules of L_{eq} and DNL, the temporal spacing between intrusive noises is irrelevant. The calculated DNL for an airfield will be the same whether all the operations are concentrated in one hour between 0700 and 2200 or spaced evenly through all fifteen of those hours. Nevertheless, there is reason to believe that concentrating operations into shorter periods can reduce annoyance. This evidence was discussed earlier in Section 3.

7.3.2 LAND USE PLANNING

Through land use planning, the receiving activity is matched to a noise exposure; it is perfectly fine to grow corn in an 89 dB environment as along as the farmer wears hearing protection, and it is perfectly fine to build a shopping mall in a 79 dB environment as long as the mall building reduces the noise to 49 dB inside. Table 7-2, reproduced from Army Regulation 200-1, provides the simplest approach to land use planning around military installations. More elaborate tables, specifying the exact land use recommended in each noise zone around airfields, are contained in Appendix A.

Noise Zone	Aviation ADNL (dBA)	Impulsive CDNL (dBC)	Small Arms PK 15(met)
I	Less than 65	Less than 62	Less than 87
II	65-75	62-70	87-104
III	Greater than 75	Greater than 70	Greater then 104

Table 7-2 Army Land Use Planning Guidelines

Under Army policy:

- **Zone I** is generally acceptable with any residential or noise-sensitive uses
- **Zone II** is normally not recommended for residential or noise-sensitive uses
- **Zone III** is not recommended with all residential or noise-sensitive uses

Because less is known about public response to the noise of gun fire, caution should be exercised when applying the tables in Appendix A to weapons ranges.

Table 7-2 should be applied on the installation even when the noise comes from outside the installation. For example, at Fort Bliss, Texas, housing exposed to a DNL in excess of 75 dB from El Paso International Airport was declared substandard and scheduled for replacement. Off the installation, DOD policy is to inform local government about the need for land use planning by providing noise contour maps developed with NOISEMAP, BNOISE2, SARNAM or other appropriate computer models. Beginning with the publication of the DOD Instruction on Air Installation Compatible Use Zones (AICUZ) in 1977, the mechanism for informing local government has been a formal AICUZ report. The report always contains recommendations on appropriate land use around the air installation that local governments are free to accept or reject. In addition to computer-generated noise contours, an AICUZ report also contains maps of runway safety zones (Clear Zones, Accident Potential Zone I and Accident Potential Zone II).

The original DOD Instruction on AICUZ only addressed planning around airbases. However, beginning in 1982, the Army expanded the AICUZ concept to cover planning around firing ranges through the Installation Compatible Use Zone (ICUZ) report. Similarly, the Navy, also concerned with extending the concept to land use planning around ranges, developed the Range Compatible Use Zone (RACUZ) report. Finally, the ICUZ report became the Installation Operational Noise Management Plan (IONMP) or in the case of the Army National Guard the Statewide ONMP, a document that addresses both what the installation can do to manage noise and what the community can do.

Any report, whether it is an AICUZ, IONMP or a RACUZ, is useless if local government and the community does not "buy into" the recommendations. Unless the installation reaches out to the local government and develops good community relations the implementation of any noise plan is doomed. The community must understand the primary mission of the installation and "the value added to the community." In the spirit of this mission, the installation needs to adopt a noise management program that is considerate of its neighbors.

In 1985, Congress authorized the Department of Defense (DOD) to make community planning assistance grants available to state and local government to help local government leaders better understand, and incorporate the AICUZ/ONMP technical into local planning programs. The DOD Office of Economic Adjustment (OEA) manages the Joint Land Use Study (JLUS) program. A JLUS is a cooperative land use planning effort between the affected local government and the military installation. The product of a JLUS is intended to present the community's rationale and justification, and provide a policy framework to support adoption and implementation of compatible development measures designed to prevent urban encroachment; safeguard the military's mission; and protect the public health, safety, and welfare.

Three criteria govern the selection of an installation for a JLUS. First, the Master Planning Office for the installation's command must have recommended the installation. Second, the installation must have completed its AICUZ/ONMP or other noise analysis report. Third, both the installation and local government must agree that a JLUS is needed. Upon acceptance of a JLUS proposal, the OEA provides matching funds to the appropriate civilian planning organization.

The JLUS is effective because it empowers local government to examine the military's findings and act on them as the community sees fit. Furthermore, the JLUS embodies military-civilian partnership in seeking solutions to a common problem.

Communities have a wide range of options in controlling land use around military installations. These include the following:

- **Zoning.** Although zoning is not effective for correcting existing noise or safety problems, it can be effective in controlling the land use density and character of uses permitted in areas that are in a state of transition from, for example, agricultural or open land to residential.

- **Special Permits.** Special permits provide a mechanism for achieving flexibility in land use in communities with zoning ordinances. In applying for a special permit, the property owner can be required to demonstrate that the proposed land use will be compatible with the noise or hazards to safety created by the Installation's activities.

- **Special Projects.** Zoning ordinances may be modified to permit planned unit developments where the buildings are clustered and the resulting open space provides a buffer between noise sources and the buildings.

- **Health Codes.** Noise standards can be added to existing health codes to promote the use of noise attenuation features in the construction of noise-sensitive buildings.

- **Subdivision Regulations**. Noise performance standards can be included in subdivision regulations. In areas that lie in proximity to the Installation's boundary, a subdivision regulation can require dedication of land as open space if impacted by noise or accident potential from aviation flight training.

- **Capital Improvements**. Local governments may have an opportunity in the planning process to structure capital improvements so as to promote land uses that are compatible with the Installation's noise and safety environs.

- **Building Codes**. Building codes can be adopted, or existing codes can be modified, to require noise attenuation features in the vertical design and construction of noise-sensitive buildings located in high noise zones.

- **Tax Incentives.** Jurisdictions with taxing authority can use tax incentives) in the form of special or preferential tax assessments) as a technique for maintaining open space in noise zones III and II, and in accident potential zones.

These options are discussed in more detail a 1988 CERL report (U.S. Army, 1988).

7.3.3 ACOUSTIC DESIGN AND SOUND PROOFING

Acoustic design includes modifications to site layout, architectural design, construction techniques to achieve noise reduction, and, for explosions or sonic booms, “rattle-proofing.” Installation planners should consider these options when reviewing plans for new military construction. Through AICUZ/IONMP and other noise reports, this information can be made available to civilian planners as well. (Please see Appendices B and C for a more detailed discussion on sound insulation structures.)

7.3.3.1 ACOUSTIC CONSIDERATIONS FOR SITE LAYOUT

Acoustic site design refers to the positioning of structures on a development site for the purpose of reducing noise levels in the most noise-sensitive buildings. Structures and natural variations in topography may serve as barriers to shield noise sensitive portions of a site. A small or earth mound can be as effective as a man-made earth berm, and depressed area may be a good location for a structure or noise sensitive exterior use.

Due to site limitations, it is most likely that shielding can best be provided by structures. Buildings housing non-sensitive uses such as parking garages are ideal for shielding.

Buildings with uses less sensitive to noise than those being protected are also potential shields. In such cases, the shielding structure will usually require acoustic architectural design and/or construction but it is possible to use retailing and administrative buildings to shield residential structures.

Although the topography of a site may not offer much opportunity for shielding, properly placed structures can exploit natural site characteristics. Simple, inexpensive ideas such as earth mounds between buildings can further enhance shielding characteristics.

Noise reflected off buildings and ground surfaces can be a significant problem, especially in high-rise buildings and exterior spaces. A street bounded by buildings becomes a noise canyon but maximizing building setbacks can mitigate this effect. Building reflection can also be reduced by varying building heights, reducing building density with the use of open space, and avoiding parallel wall canyons. Structures should be oriented to focus reflected noise into non-sensitive areas.

Setbacks can be doubly functional because they present the opportunity to utilize landscaping and other noise absorbent surface treatments, which are effective in reducing the impact of terrestrial noise sources. Hard surfaces, such as parking lots, will reflect noise (and may even amplify it) so they should be sited carefully.

7.3.3.2 ARCHITECTURAL DESIGN

Architectural techniques which can be used to reduce noise include room layout, window sizing, wall opening (doors, windows, ducts, etc) treatment, etc. These techniques, like site design techniques, are usually less expensive than acoustic construction such as wall insulation or building heavier roofs to reduce noise.

Shielding

Physically blocking or impeding sound waves can achieve noise reduction. Architecturally, there are two general approaches: reduction of wall opening surface area and utilization of external architectural elements (e.g., overhangs, balconies, etc.).

Wall Openings

The walls of a structure are sound barriers and abatement effectiveness is greatly diminished if there are passages through which sound energy can penetrate. The three common weak links in walls are ventilation ducts, windows, and doors. Methods to reduce sound transmission for each are as follows:

- **Ventilation Ducts:** Minimize the number needed on walls and roofs exposed to noise sources and place the vent away from the major noise source. When possible, use ventilation noise traps that allow free flow of the air while the bends (noise traps) in the ductwork absorb the noise. Use of acoustical treatment on vents can also cut down on noise.

- **Windows:** Minimize the window surface area (to zero if possible) on walls exposed to noise sources. Reduce the need to open windows exposed to noise sources by providing mechanical ventilation or natural ventilation through windows or ducts at unexposed locations. (NOTE: Mechanical ventilation itself requires wall openings.) Use of double or triple pane glass can also create better noise reduction.

- **Doors**: Locate entries in areas not exposed to noise. Use doors that have a magnetic seal to stop air leaks. Ensure the doors are caulked in the frame in order to reduce the noise transmission path.

Architectural Elements

Elements which are a normal part of a structure can be designed to provide a shielding effect. Shielding is most effective near acoustically weak elements, such as wall openings. Enumerated below are some of the elements to be considered in designing mitigation for traffic noise or aircraft noise:

- **Balconies:** Depending on topography and room arrangement, balconies can shield noise from below or above or balconies may reflect noise into a building. But because a balcony is often a place of relaxation, it may not be fitting to locate it in an exposed area. An analysis of times of use and of periods of unacceptable noise levels could reveal the appropriateness of balcony shielding.

- **Overhangs and Soffits***:* Can impede noise from above, but can also have reflective characteristics.

- **Shielding:** Can also be achieved by recessing a building into the ground or backfilling earth around lower floors. Case in point: a Los Angeles school district built an underground school near LAX to reduce the effects of noise.

- **Recesses:** Noise exposure is reduced in recessed areas like patios or entryways. Architectural elements such as decorative walls, protrusions or facades, may also absorb and scatter sound energy.

Most building surfaces are excellent sound energy reflectors. Built-in noise problems can be avoided by paying attention to these reflective surfaces in the following areas:

- Surface treatment can enhance or reduce sound reflection. Manufacturers of noise control materials can provide information on the reflective properties of their materials for use by acoustical engineers. Use of plants, such as ivy, can also decrease the reflection of sound from walls.

- Using rough materials or uneven surfaces that promote the scattering of sound can reduce reflection.

- As indicated previously, balconies and other overhangs can be a source of unwanted reflections. By properly locating reflective surfaces, reflected noise intrusion can be avoided. The designer should also be aware of all flat surfaces, potential reflection into outdoor spaces, and potential mini-canyons where noise might be reflected back and forth.

Rooms having noise-sensitive uses should be located away from the noise source. In residences, three categories of sensitivity are:

- **Most sensitive**: bedroom and family room
- **Sensitive**: living room and dining room
- **Least sensitive**: kitchen, bathroom, utility rooms, halls, and closets

With airplane noise, it is desirable to locate sensitive uses away from the flight track, horizontally and vertically (i.e., on the lower floors of a multi-story structure).

With all types of noise, including the noise of large caliber weapons, it is important to locate large windows away from the direction of the source. The problem arises when locating a picture window away from the source interferes with the beautiful aesthetics that a vista overlooking a military installation may provide. In those cases, the annoyance of blast noise can be reduced significantly by adding a second pane of glass with a 5 cm air gap (Schomer *et al*., 1991).

7.3.3.3 SOUND PROOFING

Soundproofing is the use of structural elements to impede sound transmission. Elements such as windows, walls, and roofs will mitigate noise to a degree, but greater abatement is possible with better acoustic construction techniques. Table 7-3 gives some approximations for the amount of sound proofing that may be achieved with different types of construction.

As indicated in Table 7-3, soundproofing can reduce noise up to 50 dB, but obviously only indoor environments can be improved. An acceptable outdoor environment is especially important in residential areas where outdoor activities are an important part of residential quality-of-life. In the mild climate of Los Angeles, for example, a study found that in areas where outdoor noise exceeded 87 dB, owners regarded the area unsuitable for residential use regardless of the effectiveness of indoor soundproofing.

The Federal Aviation Administration and the U.S. Navy have jointly published the "Guidelines for the Sound Insulation of Residences Exposed to Aircraft Operations" (Wyle Research Report WR 89-7). This report classifies U.S. residential construction under 26 categories, and "best practice" soundproofing is addressed for each category along with a cost estimate (in 1989 dollars).

TYPE OF CONSTRUCTION	AIRCRAFT AND VEHICULAR NLR in dB
Conventional wood frame – windows open	15 – 20
Conventional wood frame – windows closed	25 – 30
Conventional wood frame – no windows or ¼ inch glass windows sealed in place	30 – 35
1/8 inch glass windows, sealed in place*	20 – 25
¼ inch glass windows, sealed in place*	25 – 30
Walls and roof – weighing 20 to 40 lb/sq. ft, no windows*	40 – 45
Heavy walls and roof – weighing over 80 lb/sq. ft, no windows	45 – 50

Note: Assuming surface area consisting only of this element

Table 7-3 Approximate Noise Level Reduction (NLR) for Different Types of Construction

In general, acoustical engineers address the following seven elements when designing soundproofing:

- **Walls:** Increase mass. Use "dead" air spaces; increase airspace width (between walls); increase airspace length (space between studs); use staggered studs; seal cracks and edges; use insulation blankets; give special attention to openings, electrical outlets, medicine cabinets, etc.; use resilient materials to hold studs and panels together; use acoustic coatings

- **Roofs:** Increase mass; seal cracks and edges

- **Ceilings:** Use insulation blankets non-fixed suspension methods acoustic coatings

- **Floors:** Block off all joists (prevents noise from traveling over or under walls), use resilient supports between joists and floor.

- **<u>Windows</u>:** Use sealed windows, increase glass thickness, use double glazed windows, and increase volume of "dead" airspace in double glazed windows.

- **<u>Doors</u>:** Use solid core doors (not sliding or hollow core) and doorframe gaskets.

- **<u>Interior Design:</u>** Use heavy drapes, heavy carpets, and acoustic ceiling treatment.

7.3.3.4 RATTLE PROOFING

Inaudible low frequency sound can cause parts of a building to vibrate or rattle. When this happens, the occupants are much more annoyed than they would be if they experienced the same sound without the rattle. Some of the sound proofing techniques discussed above will reduce the amount of interior rattle, but even a solid building may contain architectural features prone to rattle. Building rattle is primarily a problem in areas exposed to the noise of large caliber weapons, but helicopter operations can also generate rattle within a kilometer of homes.

Rattle proofing is different from soundproofing. A November 1987 CERL report, "Expedient Methods for Rattle-Proofing Certain Housing Components," contains a list of **"DO's"** and **"DON'T's"** for eliminating or reducing building rattle caused by low-flying helicopters and blast waves. The following are some of these suggestions:

<u>Windows</u>

There are seven basic types of windows: fixed, casement, awning, sliding, double-hung, jalousie, and pivoting.

DO use a fixed window if outdoor air is not required.

DO use a casement or awning window that can be secured firmly against a gasket.

DO use gasket material liberally to reduce the gap between the sash and track and to soften the impact when these two components make contact. A second advantage is the improved reduction in heat loss.

DO encase the double-hung window sash weight in a soft plastic jacket to soften the contact when the weight vibrates.

DO apply a small felt disk to the lower edge of a jalousie window element to prevent window-to-window contact. Manufacturers should bond a soft plastic sleeve to window edge to prevent heat loss and rattle.

DON'T allow the jalousie window opening mechanism to become loose and worn. All shafts should rotate in soft plastic bushings. All gear clearances should be minimized. Linkage should be encased in soft plastic sleeves.

DON'T allow the window hardware to loosen. Inspect the hardware periodically and apply preventive maintenance.

DON'T use a sliding, double-hung, jalousie, or pivoting window as a new or replacement window due to the gaps, which exist between the sash and track.

Doors

Doors operate by: swinging, bypass sliding, surface sliding, pocket sliding, and side-hinge folding. Door-types include flush, paneled, French, glass, sash, jalousies, louvered, shuttered, screen, and Dutch doors

DO use swinging paneled doors for the home exterior. Swinging and side-hinged folding doors should be used in the home.

DO use a single- rather than a multiple-element garage door. Weather-strip the building jamb and allow minimal clearance between the overhead track and roller. Encase the springs in soft plastic jackets.

DO avoid French, Dutch, jalousie, louvered, and shutter doors. If used, separate the door elements using soft plastic foam or weather-stripping-type materials.

DO use a plastic screen instead of a metal screen.

DO insure that the door hardware is in good repair. Minimize the gaps in lockset tongues where the tongue fits in the jamb. Insure that hinge pins are tight and coated with plastic. Place a soft plastic foam or felt strip on door mail slots to prevent hard contact.

DON'T use lightly constructed screen doors. Enclose the safety chain in a soft plastic sleeve and insure that the hardware is tight and in good repair.

DON'T use sliding doors, particularly the pocket sliding type. If sliding doors must be used, do not hang the door loosely from the ceiling but use a bottom track also. The gap between the track and the door should be minimized. A track liner of soft plastic or weather-stripping-like material will minimize contact.

Ceiling Systems

DO insure that enclosed lighting fixtures are well made with minimum gaps. Insure that the sheet metal housing is stiff and well secured at its contact points.

DON'T use a dropped acoustical tile ceiling. If one is used, insure that contact between vertical wires and joint and metal frame is eliminated.

DON'T use light fixtures that hang from the ceiling by a chain or similar devices. Also avoid light fixtures with loose elements.

Miscellaneous Items Including Bric-a-Brac

DO install soft plastic foam or weather-stripping-like material to the lower edge of the back of the hanging mirrors and picture frames to prevent direct contact by the frame or mirror with the wall.

DO separate small items placed on shelves, in closets, or on other horizontal surfaces from these surfaces by using small felt or foam disks or strips glued to the underside of the item.

DO separate plates placed horizontally on shelves using soft plastic foam doilies.

DO insure that window air-conditioners are installed properly. The refrigeration coils should be separated. Foam strips or disks should separate air intake and exhaust louvers.

DO keep downspouts and gutters in good repair. Insure that all seams are tight and covered with duct tape.

DON'T allow home heating ducts and registers to loosen. Use duct tape around all seams.

7.3.4 PUBLIC INTERACTION AND EDUCATION

The more negative an individual's attitude toward a noise producer, the more intolerable the noise itself is likely to be. The reduction of ill feelings can decrease the incidence of complaints and will have positive peripheral affects in other dealings with the on- and off-installation public. The responsibility for enhancing an installation's public image lies with all personnel who deal with the public. In the case of noise problems, this responsibility lies primarily with the Public Information Officer, the installation planner, the Public Affairs Office (PAO), and those who respond to the specific noise complaints. A Tri-Service Community and Environmental Noise Primer titled "A Primer on Facilitating Community Involvement and Communication with the Public is available from the Army Center for Health Promotion and Preventive Medicine (USACHPPM, 2005). This primer is an introduction to DOD environmental noise issues, management, and resources, with an overview on using community involvement to generate support for noise management planning and abatement activities. The entire primer is available electronically on the companion CD along with a lot of community involvement information, ready-to-use fact sheets, and direct Internet links to important Web sites and electronic resources.

These tools are intended for all Army personnel (including an installation and/or garrison commander, a master planner, and public affairs staff) who might communicate with the public about any noise-related matter. It will also be useful to those who are likely to have noise management responsibilities such as range control, environmental management, and the Staff Judge Advocate's office (though this will vary from installation to installation).

Beyond the usual courtesies extended to persons making inquiries and registering complaints, installation personnel should be as informative as possible. Helpful information might include explanations of why operations must occur when they do, why they must occur at a particular installation, or why operating the noise source is necessary. Although such information will not lessen the adverse effects experienced during a particular incident, it will hopefully reduce further alienation and resultant intolerance. Disseminating information about the execution of specific abatement techniques or any other positive measures is particularly important. In essence, people want to know if there is a prevailing reason why they must be subjected the noise situation. Furthermore, they do not want to be ignored.

7.3.4.1 MODIFYING ATTITUDES

Some experts believe that attitudes about the noisemaker are as important in predicting annoyance to noise as are the measurable decibels. In a review of social surveys, the Australian researcher, R.F.S. Job (1988) concluded, "only a small percentage (typically less than 20%) of the variation in individual reaction is accounted for by noise exposure."

A study published by Fields (1993) is perhaps the most definitive study on the importance of attitudes in noise annoyance. After examining 464 findings drawn from 136 surveys, Fields found noise annoyance to be related to the amount of isolation from sound in the home (sound proofing) and the following five attitudes (several of which can be changed through public education):

- **General Noise Sensitivity:** Of the five attitudes identified by Fields, noise sensitivity is the only one that cannot be changed through public education. Some people are just more bothered by noise than others. There is even a standardized psychological test to differentiate noise-sensitive people from those who are relatively insensitive to noise (Weinstein, 1978). People who are noise-sensitive do not choose to be noise-sensitive; it's part of their physiology. In addition, it's common knowledge that people become more noise-sensitive when they are ill. So there is nothing that representatives of the installation can do to change noise-sensitivity but they can, however, recognize that it exists and treat complainants with respect.

- **Fear of Danger from the Noise Source:** This attitude is primarily a factor in aircraft annoyance and generally does not apply to gun noise. Simply put: when people are afraid of an airplane flying over their house, they will be more annoyed by the sound of the airplane.

- **Noise Prevention Beliefs:** If people believe that the installation has a choice about making noise, they will be much more annoyed by the noise exposure than if they believe that there was no choice. The importance of this attitude underscores the vital role that the Public Affairs Office plays in noise mitigation. As fewer numbers of the U.S. population serve (or have a loved one serve) in the Armed Forces, the citizenry is becoming less aware of the need for the soldier to train over larger and larger expanses of land, at all times of the day and night, and with more and more powerful weaponry. Naturally, people exposed to military noise will ask why training couldn't be moved to some other location, and PAO's success in answering these questions can be worth many decibels in source reduction or path modification.

- **Beliefs about the Importance of the Noise Source:** People rarely complain about a MEDEVAC helicopter bringing a patient to a shock trauma facility, but they frequently complain about news or traffic helicopters. Clearly, everyone understands the importance of the life-saving mission. Within Germany, acceptance of noise from U.S. military operations waned during the 1980's. At the beginning of that decade, most German citizens recognized the threat of the Soviet Union, and people tolerated the noise exposures which would have been labeled "normally incompatible with residential use" under DOD guidelines. By mid-decade, there was a growing sense that the Soviet Union was a "paper tiger" rather than an imminent threat and the German Federal Ministry of Defense became a party to lawsuits aimed at reducing noise levels from U.S. training. With the fall of the Berlin Wall at decade's end, the threat dissipated entirely and German authorities began asking that U.S. Army ranges comply with often more stringent German noise laws. Once again, the PAO is the lead player in trying to convince the installation's neighbors about the importance of military noise. Through press releases, the PAO can work to establish a connection between training and deployment. For example, if people understand the human suffering caused by the indiscriminate use of mines in various "small wars," they will probably be more accepting of explosions from mine clearing devices.

- **Annoyance with Non-noise Impacts of the Noise Source:** Contemporary installation commanders devote much time and resources to working with local communities, and one of the expected payoffs is a reduction in annoyance about training noise. For instance, if people are annoyed by dust and noise from a nearby tank trail, eliminating the dust can be expected to lower annoyance about the noise. By working to reduce all adverse environmental effects from military training, the installation commander can avoid unnecessary complaints about noise.

7.3.4.2 PUBLIC RELATIONS

Establishing a Public Relations Program

A positive public relations program should be implemented regardless of the manner in which noise abatement is approached. Towards the creation of such a program, the planner should endeavor to:

- **Prepare selected individuals to deal with the public**. Inform personnel who handle complaints and inquiries about noise and its abatement. (This manual contains the background information they will need)

- **Set up a standard procedure for receiving and responding to inquiries and complaints.** This procedure should ensure that letters are answered promptly and that complete information about incidents is collected. A checklist for telephone complaints will facilitate data collection.

- **Have all noise-related grievances and questions channeled to the specially prepared personnel.**

- **Ensure that those who operate and work with noise producing devices are informed of their responsibilities.** This includes information about special problems (including those revealed through complaints) and this training should also be administered regularly as a preventative measure.

- **Provide information on operations and noise abatement efforts to interested citizen groups and public agencies.**

Advance Notification

When the schedule calls for a period of intense activity from an exceptionally noisy training operation, it is a good idea for the Public Affairs Office to inform the public through the local newspapers, TV, and radio stations. This practice has proven particularly successful at Fort Bragg (Marine artillery training), Fort Lewis (artillery training), and at some Marine Naval Air Stations (carrier flight practice). When people know about noisy operations in advance, they can prepare themselves and their families for the situation. For example, some dogs react to the booms of artillery with nervousness and barking, and their owners might be able to isolate their pets in advance of firing. Similarly, reports have been received about small children being disturbed by artillery noise at night; if parents know about the booms in advance, they can prepare their child for the disturbance.

Toll-Free Complaint Number

Several military installations have been successful in publishing a toll free noise complaint telephone number in local newspapers. Although some callers could be characterized as "irate," many callers are simply seeking information on what is making the disturbance and when it will stop. The toll-free complaint number provides the Public Affairs Office an opportunity to explain why a particular disturbing operation is needed for training. In setting up a telephone number, it is important to ensure that callers can get through to someone. NOTE: The most successful complaint management programs allow the complainants to talk directly with operations rather than to a middle person.

Complaint Follow-up and Investigation

Rapid response to public inquiries is essential in any program under the purview of an installation's Public affairs Office. An analysis of complaints about Army noise published in the Journal of the Acoustical Society of America in 1983 (Luz *et al*., 1983) demonstrated that people whose complaints had been ignored were angrier than those who had received a rapid response.

7.4 Tri-Service Community and Environmental Noise Primer: A Primer on Facilitating Community Involvement and Communicating with the Public.

This primer can help safeguard your installation's mission, ensuring that Soldiers, Sailors, Airmen and Marines are trained and ready when needed. The primer is an introduction to DOD noise issues, management, and resources, with an overview on using community involvement to generate support for noise management planning and abatement activities. The entire primer is available electronically and can be downloaded or launched from this site or available in print with a companion CD along with a lot of how-to-do community involvement information, ready-to-use fact sheets, and direct Internet links to important Web sites and electronic resources.

These tools are intended for all DOD personnel who might communicate with the public about any noise-related matter including a base/garrison commander, master planner, and public affairs staff. It will also be useful to those who are likely to have noise management responsibilities. Installation personnel involved in noise management will vary from installation to installation, but will likely include range control, environmental management, and the Staff Judge Advocate's office. Many other installation personnel will also benefit from a better understanding of environmental noise and its impacts on both neighboring communities and military operations.

This document is an initiative of the Defense Noise Working Group (DNWG). The DNWG provides the single authoritative voice for the DOD in the area of:

- Developing scientific and policy foundation for community/environmental noise effects, mitigation, prediction, noise management, and outreach capabilities
- Coordinating and recommending policy
- Endorsing official DOD noise models and databases
- Coordinating research between services
- Reviewing Service proposals

This Primer was developed by the U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM) Operational Noise Program, Risk

Communication Office, and WPI, a Virginia Tech affiliated corporation. The conversion of the Primer from an Army specific publication to a Tri-Service document was funded by the U.S. Air Force. The Primer is available from USACHPPM or downloaded from:

http://chppm-www.apgea.army.mil/dehe/morenoise/

7.5 SUMMARY

This final chapter, more than any other, has demonstrated how planning in the noise environment requires teamwork between the commander and his/her staff. Although mitigating noise at the source is the work of the acoustical engineer, mitigating noise along the path requires teamwork between the installation planner, the military trainers, and the controllers of airfields, air space, and ranges. Finally, mitigation at the source requires a command presence and cooperation between the PAO, legal offices, and planners in both the military and civilian community.

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APPENDIX A

NOISE COMPLAINT GUIDELINES

A.1 INTRODUCTION

When the Untied States Environmental Protection Agency (EPA) recommended using the Day-Night Level (DNL) in 1974, their experts justified the decision with data on community response, including noise complaints. To improve the statistical relationship between the DNL and community response, the EPA experts introduced corrections for past experience and for the background noise in each community. As documented in Appendix D of the EPA report, people were most likely to complain when they lived in quiet areas and when they were unaccustomed to the noise. These observations were consistent with later analyses of Air Force and Army noise complaints showing an association with short term increases in DNL rather than the annual average DNL (Luz *et al*., 1983).

As noted by Fidell (2004), “complaints were abandoned as a measure of community reaction to noise at the federal level in the 1970s largely because of the promise that Schultz’s relationship seemed to offer. At the time, noise complaints were difficult to process and systematically compare, largely inaccessible to researchers, and generally awkward to interpret.” Fidell also noted that “these limitations have lessened over the last decade as computer-based aircraft noise and operations monitoring systems have become commonplace at major airports, and as geo-information system software has come of age.”

For the DOD, noise complaints never lost their relevance. DOD planners use DNL to try to convince people not to move into noisy areas, but once people are there; DOD operators manage by noise complaints. For the operator, the question becomes simply, “What decibel level will be tolerated without complaint?” Of course, individuals vary but some generalizations about community response to different levels can be made. The purpose of this Appendix is to document those levels for the major sources of concern: aircraft, helicopters, small arms, large weapons, and intermediate weapons.

A.2 COMPLAINT THRESHOLD FOR JET AIRCRAFT

<u>Daytime Threshold</u>

For jet aircraft, several experts have identified a maximum A-weighted level of 70 dB as a threshold for annoyance. Among the first to suggest a threshold of 70 dBA were Rylander *et al*. (1972). In the course of studying community annoyance around Scandinavian airports, they found that annoyance was closely related to the maximum level of the three noisiest flights/24 hours. When the maximum level of the three noisiest flights was 70 dBA, only 5% of the exposed population described themselves as very annoyed. Over the range of 1 to 50 flights, annoyance increased according to the general rules of LEQ. Beyond 50 flights per day, annoyance depended on those three noisiest flights. Table A-1 shows the relationship reported by Rylander *et al*. (1974) for people exposed to from 50 to 189 flights per 24 hours.

Maximum Level, dBA	Percentage Highly Annoyed
70	5
75	13
80	20
85	28
90	35

Table A-1 Percentage of Population Highly Annoyed by Aircraft Noise

In explaining their conclusions, Rylander *et al*. (1974) identified 70 dBA as the threshold for interference with conversation, and they backed up this statement with a composite graph of conversational interference data from the Munich, Yokota (Japan), Amsterdam and Scandinavian airports. The graph showed interference going from near zero with maximum levels of 70 dBA to more than 90% above 100 dBA. More recently, an Australian aircraft noise expert used the same rationale in choosing the 70 dBA contour as a supplemental noise metric. Southgate (2000) identified 70 dBA as the trigger level likely to disturb conversation and/or listening inside a house with open windows. This Australian initiative targets the individual, not the community. For example, before making a house purchase, an individual has the opportunity to examine the 70 dBA contour and form their own judgment on whether the aircraft noise at a particular location is likely to be acceptable.

In effect, the 70 dBA contour serves as a “caveat emptor” to warn the most noise-sensitive people that they might not be happy with aircraft noise in a particular neighborhood. The 70 dBA contour cannot be used to limit development or limit flight operations because the vast majority of the population is not bothered at these noise levels. In Norway, land is considered suitable for new residential construction as long as the maximum level exceeded three or more times during the week is below 85 dBA (Bugge *et al*., 1986). An area is considered unsuitable for homes if the maximum level of the three (or more) weekly flights exceeds 100 dBA during the day or 90 dBA during the night. Santa Monica, California, has imposed a maximum noise limit equating to 83 to 88 dBA at 1,500 feet from the end of each runway.[2]

Awakening Threshold

Setting a threshold for noise complaints during nighttime sleeping hours is more complex than setting a day threshold. When we are sleeping, lower brain centers continue to scan for novel sounds, since novel sounds are sometimes associated with danger. Consequently, unusual sounds at relatively low decibel readings can result in awakening. Given an opportunity to habituate to the normal sounds in their bedrooms, most people learn to sleep through very loud sounds without awakening.

A study conducted by the acoustical firm of Hanson, Miller, Miller and Hanson (HMMH) at Mather Airfield in Sacramento, CA, provides evidence that for some people, the threshold for awakening from jet aircraft is below 70 dBA (HMMH, 2003).

Mather Airfield is the former Mather Air Force Base. When preparing for the reuse of the air base, Sacramento County implemented a text book example of responsible land use planning for areas adjacent to the airport. Mather Airfield evolved into air cargo center, but with the growth of the air cargo business, a number of people living in DNL 55 complained about sleep disturbance from night flights. As part of the effort to manage these complaints, the Sacramento County Airport System (SCAS) ran a 120-day test offering pilots a VHF Omni-directional Range/Distance Measuring Equipment (VOR/DME) approach corridor during nighttime hours (2200 to 0700). Pilots were also free to use the Instrumented Landing System (ILS). The test began on July 15, 2003. SCAS also contracted with HMMH to measure noise levels at eight sites along the approach to runway 22L. Four sites were quieter with the VOR/DME approach, and four were quieter with the ILS approach.

Mather Airfield is not a busy airport. Normal air cargo traffic consists of about 6 arrivals per day. Yet during the test period, SCAS received 4,019 noise complaints with 1,987 related to nighttime operations.[3] In one neighborhood (El Dorado Hills), 140 callers generated 939 complaints over the 120 day period. Of these, 496 complaints from 83 callers were about nighttime operations. In El Dorado Hills, the median maximum levels ranged between 55 and 65 dBA (two sites, two measurement

[2] Santa Monica's Airport Ordinance specifies a Single Event Noise Exposure Level (SENEL) of 95 dB. The maximum level is usually 7 to 12 decibels below the SENEL.

[3] Complaint statistics were published at http://www.sierrafoot.org/local/noise/complaints.html

weeks), and the highest maximum was 76.6 dBA. There were more complaints from the novel VOR/DME approach (626 complaints) than from the more familiar ILS approach (243 complaints).

In spite of the large number of complaints associated with relatively low levels at Mather Airfield, the available evidence suggests that a fly over at a maximum of 70 dBA is unlikely to awaken people who have had the opportunity to habituate. This evidence has been published on the website of the Federal Interagency Committee on Aviation Noise (FICAN) and is reproduced here as Figure A-1.

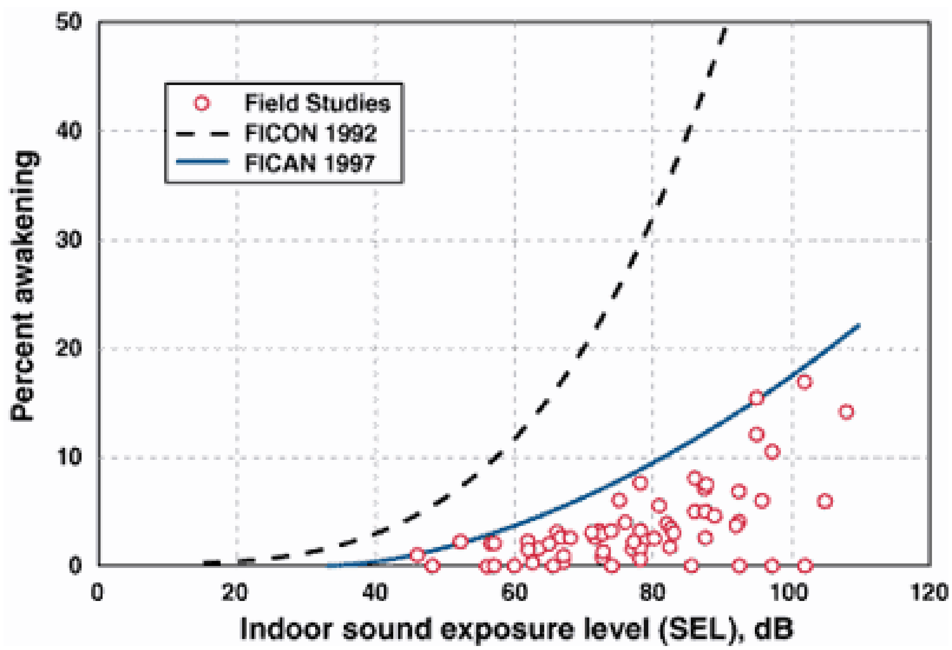

Figure A-1 FICON and FICAN Sleep Disturbance Curves for Familiar and Unfamiliar Sounds

The X-axis in Figure A-1 has units of Indoor Sound Exposure Level (SEL). For most jet aircraft over-flights, the outdoor SEL is on the order of 7 to 12 dBA higher than the maximum level. Thus, the 70 dBA maximum equates to an SEL of 77 to 82 dBA. For people sleeping with open windows, the outdoor-to-indoor attenuation is about 15 decibels. From Figure A-1., the expected probability of awakening with an indoor SEL of 62 to 67 dBA is below 5%.

A.3 COMPLAINT THRESHOLD FOR HELICOPTERS

Daytime Threshold

Most studies of community response to aircraft noise are for fixed wing aircraft. Consequently, it is more difficult to set a complaint threshold for rotary wing aircraft. Rotary wing aircraft seem to be more noticeable than fixed wing aircraft. For example, at the Decatur Illinois Airport, where the DNL was determined by fixed wing aircraft and there were less than two UH-1H operations per week, 7% of the people exposed to a DNL of 66 dBA reported themselves to be "highly annoyed" by helicopters (Schomer, 1983). Whether being more noticeable translates into a lower complaint threshold is not known. Based on the following four observations, using the same 70 dBA contour for fixed and rotary wing noise appears reasonable:

- In the helicopter annoyance study published by Fields and Powell (1987), the maximum level of the quieter over-flights was 75 dBA. As the daily number of flights at this level increased, annoyance increased as a function of the nine-hour LEQ.

- Pima County, Arizona, adopted an Airport Environs and Facilities noise regulation in which no helicopter is allowed to exceed a maximum of 75 dBA in noise-sensitive zoning.[4] Pima County also limits the number of daily operations to ten. Over the range of 1 to 8 operations, the maximum noise level is lowered in order to maintain a constant LEQ. With 8 operations, the limit is 60 dBA.

- Tasmania adopted a limit of 82 dBA for a single operation.

Complainants in Erlensee, Germany, who live near a flight corridor used by U.S. Army aviators at Fliegerhorst Army Airfield, are seeking to eliminate over-flights at maximum levels between 70 and 80 dBA.

Awakening Threshold

Without further research, it is unclear whether the FICAN sleep disturbance curve provided in Figure A-1 applies to both fixed and rotary wing noise. There are two reasons to suspect a difference. First, an approaching helicopter is heard for a longer period of time than a jet aircraft. Leverton (1997) noted that the maximum noise level is a poor predictor of helicopter detection threshold. Schomer and Wagner (1996) demonstrated that the helicopter detection rate of Ss in homes near a railroad and approach to a military airfield grew at 3 times the rate found for trains or for airplanes near LAX. Second, the predictive relationship in Figure A-1 is based on SEL, not maximum level. For helicopters, the difference between the maximum level and the SEL is larger than for jet aircraft.

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[4] Pima County posted their code at http://www.co.pima.us/cob/c.a2.htm

A.4 COMPLAINT THRESHOLD FOR SMALL ARMS RANGE NOISE

Daytime Threshold

A study conducted by the Bavarian Environmental Protection Agency found a low probability of noise complaints when gunfire was between 50 and 60 decibels, A-impulse (dBAI), with a sharp rise in complaints as the level increased above 60 dBAI (Heiss, 1978). Similarly, Sorensen and Magnusson (1979) reported minimal annoyance among Swedes exposed at 48 to 65 dBAI with a sharp rise above that level. Sorenson and Magnusson's corresponding threshold for dBA fast was 60 and for dBC peak was 80. Hede and Bullen (1982) interviewed Australians living near a civilian small arms range and found that none were seriously affected when the linear peak level was below 75 dB. Shooting at this range was confined almost exclusively to weekends, mainly in the afternoons, with approximately 150,000 shots fired annually. Hede and Bullen concluded, "it would appear then, that a mean unweighted peak sound pressure level around 85 dB would be a reasonable criterion for land-use planning. At this level approximately 10% of a residential population would be expected to be seriously affected." In a later study at a more active military range in Williamstown, Hede and Bullen confirmed this limit with a caveat. Their research group wrote: "it should be assumed that the 85 dB LPEAK criterion will only be valid for Williamstown up to 1,000,000 rounds per year. For other rifle ranges, the criterion should hold provided that there are no substantial, and particularly sudden, increases over the long-term average activity for a given range (O'Loughlin *et al*., 1986)." The group took a slightly more conservative approach to new and expanded ranges; "When a new range is opened or there is a substantial increase in activity, it would be sensible to adopt a more conservative criterion. A level of 80 dB LPEAK may reasonably be adopted until further research into this aspect is undertaken."

Awakening Threshold

There are no field studies of sleep disturbance from small arms fire. In practice, the question is not important for range operators, because small arms ranges are rarely used after dark. If firing with night vision devices becomes important in the future, it may become necessary to conduct research to establish the threshold for awakening.

There are training areas where blank ammunition is fired at night. For example, the former Sudbury Annex in Maynard, Massachusetts, had been used for night training prior to its conversion to a wildlife protection area. On 26 March 1983, residents collected 620 signatures on a petition stating "we are opposed to the emotional and environmental impact of the weapon noise on ourselves and our children and we hereby request the immediate cessation." A subsequent study showed that the awakening was due to grenade and artillery simulators rather than blank 7.62 mm ammunition (AEHA, 1983). Because night training generally incorporates both simulators and blank ammunition, predictions of awakening at similar training areas should be based on the awakening threshold for large weapons.

A.5 COMPLAINT THRESHOLD FOR LARGE WEAPONS AND EXPLOSIONS

Daytime Threshold

Experience has shown that linear peak does a good job at capturing the low frequency energy responsible for noise complaints and damage claims about large weapons and explosions. Research conducted by the Bureau of Mines established that the bandwidth of the sound measurement system is important for predicting structural damage (Siskind *et al*., 1988). The recommended limits for different bandwidth measurements are shown in Table A-2. As reported by Hubbard (1982), typical U.S. wood frame homes resonate in the range of 12 to 30 Hz, and if one measures with sound analyzers sensitive to even lower frequencies, those lower frequencies add to the decibel reading without adding to the structural damage. Installations interested in avoiding damage claims adhere to the Bureau of Mines limits. For example, Aberdeen Proving Ground has an absolute limit of 130 dBP, and McAlester Army Ammunition Plant has an absolute limit of 128 dBP.

Based on minimal probability of the most superficial type of damage in residential-type structures, any of the following represent safe maximum air blast levels.

• 0.1 Hz high pass system	- 134 dB
• 2 Hz high pass system	- 133 dB
• 5 to 6 Hz high pass system	- 129 dB
• C-slow (events < 2 sec)	- 105 dB

Table A-2 U.S. Bureau of Mines Recommendations on Microphone Design Needed to Measure Air Blasts

The threshold for complaints is significantly lower than the damage threshold. Two procedures for predicting blast noise complaints were published in the 1970's. The first was published as Appendix G in the EPA (1974) Levels Document. As shown in Table A-3, the guideline incorporated the principle of equal energy (LEQ) in the same way as Pima County, AZ, did for their helicopter noise limits. In the EPA procedure, no blast is allowed at 126 dBP or higher.

Blast Level (dBP)	Permissible Daily Number
Above 125	0
123-125	1
121-122	2
120	3
119	4
118	5
117	6
116	8
115	10
114	12
113	16
112	20
111	25
110	32
109	40
108	51
107	64
106	80
105	100

Table A-3 EPA (1974) Recommended Limits for Blasts and Sonic Booms

The second procedure was developed by Pater (1976) to manage noise complaints at the Naval Surface Weapons Center, Dahlgren, Virginia (Table A-4). The upper limit of the EPA procedure falls inside Pater's "moderate complaint risk" category.

A study conducted at Aberdeen Proving Ground in which known complainants were asked to rate individual blasts is reproduced from Luz *et al*. (1994) as Figure A-2. Each point in this graph represents the average level of blasts rated by one of the words on a five point annoyance scale, i.e., not annoying, slightly annoying, moderate annoying, very annoying or extremely annoying. One complainant reported a shot as "worse than ever" and this one shot is reflected as a single point on the graph. For the three most sensitive complainants, the average peak level for blasts rated as "slightly annoying" ranged between 105 and 110 dBP. This finding is consistent with Pater's conclusion that blasts below 115 dBP have a low risk of noise complaints.

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

Table A-4 Blast Noise Complaint Guidelines from Naval Surface Weapons Center (Dahlgren, Virginia)

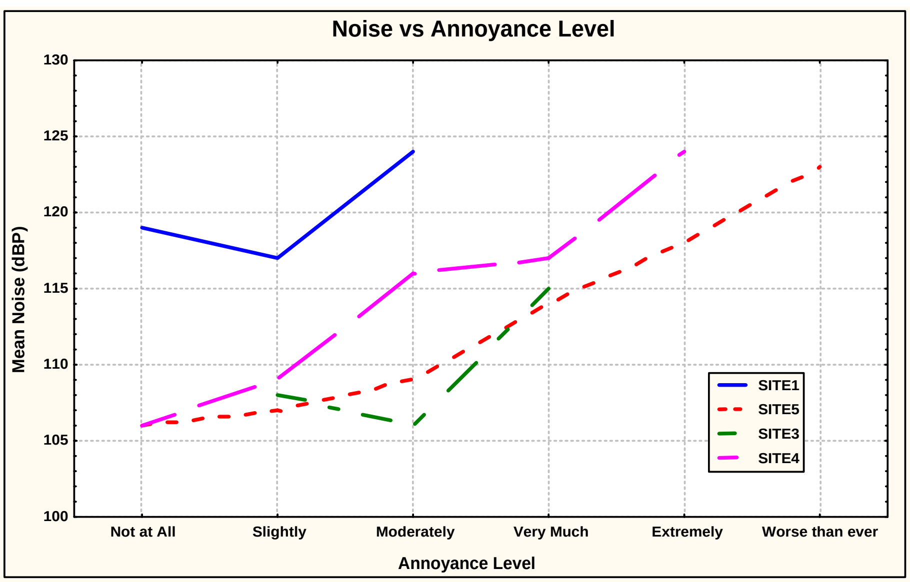

Figure A-2 Average Peak Level of Blasts Assigned to Different Annoyance Categories by Complainants Listening to the Blasts in Their Own Homes

Awakening Threshold

Research on the awakening threshold for blast noise is the subject of current research from the Army Construction Engineering Research Laboratory.

A.6 COMPLAINT THRESHOLDS FOR MEDIUM WEAPONS

Daytime Threshold

Since the 1970's, Army environmental noise assessments have divided weapons into two categories: (1) small arms, (2) weapons of 20 mm caliber or larger. When it comes to single event limits, this dichotomy entails a large disparity. On the one hand, the suggested complaint threshold for small arms is 85 dBP, and on the other hand, the suggested complaint threshold for larger weapons is 115 dBP. Certainly, much of this 30 decibel disparity is attributable to differences in the volume of fire. The annoyance of gun fire follows the principle of equal energy (LEQ), and it may be reasonable to equate the annoyance of one blast at 115 dBP with 1,000 impulses at 85 dBP. Nevertheless, such a comparison masks an important difference in sound quality. A medium caliber weapon, such as the 25 mm gun on the Infantry Fighting Vehicle, annoys people because it sounds like someone hammering at the door. House vibration is minimal, but the impulsive sound can still be annoying.

Currently, DOD noise experts do not have a way of capturing the unique annoyance of medium caliber guns. Two European experts, Buchta (1996) and Vos (1996), have proposed a method for equating the annoyance of different caliber weapons by measuring each impulse with both A and C weighting. Their results showed that an almost perfect prediction of annoyance, as rated indoors with the windows closed, is obtained on the basis of the weighted sum of (outdoor) ASEL and the product of (CSEL-ASEL) and ASEL. A caveat is that typical U.S. construction is not as solid (vibration-free) or energy-efficient (acoustically-attenuating) as typical European construction. The European work warrants further study in the context of U.S. construction practices.

Awakening Threshold

As a practical matter, the threshold of awakening for 25 mm gunnery is not of concern, because Infantry Fighting Vehicles generally train on the same Multi-Purpose Range Complexes as the Main Battle Tank. If people aren't awakened by the 120 mm gun, then they are not likely to be awakened by the 25 mm gun.

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APPENDIX B

SOUND INSULATING HOMES AGAINST AIRCRAFT NOISE

B.1 INTRODUCTION

Often a structure simply *must* be subjected to noise. But in situations where the building may have existed before the noise became an issue, where there was little choice as to where the building could be located, or where zoning considerations relegated the structure's specific type or function to particularly noisy areas, the construction of the building itself has an enormous impact on the quality of the environment inside the building. Proper architecture can greatly reduce the effects of outside noise on the people inside the buildings. Conversely, with improper construction style, materials, or techniques, buildings can actually amplify the irritation of outside noise.

The illustrations and some of the text in this Appendix have been copied from a document written in August 1998 by John S. Bradley, National Research Council of Canada Institute for Research in Construction. J.S. Bradley is a Fellow of the Acoustical Society of America. He prepared Sound Insulating Homes Against Aircraft Noise for the Canadian Department of National Defense. While much of the information in this document relates specifically to aircraft noise and homes, the principles described hold true for many other types of noise and structures (please see Appendix C for a discussion on low frequency and blast noise.

The Canadian government did not intend this document to be a design guide. As stated in the original document, "The design of a well-insulated home to adequately protect the residents in a noisy area is a very complex subject. Solutions are usually much cheaper at the design stage. Improving sound insulation in existing buildings is usually much more expensive." Just so, the purpose of this Appendix is to point out options for aircraft mitigation, not to serve as a design book.

The Canadian government further advised, "Those contemplating building a home in an area exposed to significant aircraft noise or where aircraft noise may be expected to increase in the future should contact an acoustical consultant with experience in this area. This is probably the most cost effective means of providing an acceptable indoor environment." This bears repeating for U.S. citizens as well. An alphabetical list of members of the Institute for Noise Control Engineering of the USA can be found on that organizations website at:

http://www.inceusa.org/members/members.asp

INCE-USA has a process for board-certifying acoustical engineers, and persons on the list are so identified.

Another useful resource is a report published in 1989 by Wyle Laboratories, Arlington, Virginia, for the Naval Facilities Engineering Command and the Federal Aviation Administration. Wyle Research Report WR 89-7, Guidelines for the Sound Insulation of Residences Exposed to Aircraft Operations, explains how to improve sound insulation in existing buildings. Because construction practices vary greatly across the regions and climates of the U.S., the Wyle report addresses mitigation for 26 separate house designs. The greater complexity is probably not a problem for the target audience (General Contractors, City Agencies and Architect/Consultants), but the typical layperson would be expected to have difficulty in sorting through the options. In 2004, the Navy and FAA funded Wyle Laboratories to work on a more "user-friendly" update. In the meantime, the outlined used in the Canadian publication is useful in conveying the basic principles for protecting interior spaces from aircraft noise.

Section 2 below explains the basic principles of sound insulation. This is followed by a discussion of the importance of site and building layout in Sections 3 and 4. Section 5 explains the sound insulating properties of walls, but the more important topics of windows and doors are considered separate in Sections 6 and 7. Sound insulation issues related to roofs are discussed in Section 8. The importance of chimneys, vents and other openings are presented in Section 9 and Section 10 reviews the relative importance of the various issues.

A more recent publication developed by Wyle Laboratories (2005) for the Department of the Navy further refines guidelines for sound insulation of residences exposed to aircraft operations.

B.2 BASIC PRINCIPLES

How Outdoor Sound Propagates into a Home

Outdoor sound can enter a building in two ways. First, it can enter through an opening (e.g., an open window). Second, it can cause some part of the building to vibrate so that the vibrations create sound in the indoor air (e.g., the glass in a closed window). Both paths must be considered for effective outdoor-to-indoor sound attenuation.

Making Better Barriers to Sound

There are 5 key factors to creating better barriers to sound. These apply not only to various building façade elements such as walls (internal and external) and roofs but also to sub-components such as windows and doors.

- **Mass of Outer Layers**

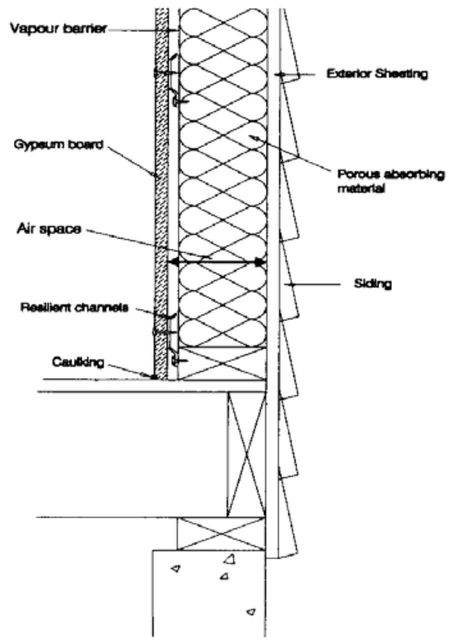
  The mass of the surface layers is the most important parameter, and heavier walls, such as brick and masonry constructions, are better barriers to sound. Still, the mass of a wood-frame wall can be increased by adding multiple layers of gypsum board on the inside or additional layers of external sheeting on the outside.

- **Vibrations Breaks Between Outer Layers**

  Typical U.S. homes are wood stud, Western framing, with gypsum board on the inside and various other layers on the outside. A wall will be a much better barrier to sound if there is a structural break between the interior and exterior layers. Usually this is achieved by mounting the gypsum board on special resilient channels (sometimes referred to as resilient furring strips) made of lightweight sheet metal. These are illustrated in Figure 1. The resilient strips act like springs and create a resilient vibration break between the gypsum board and the rest of the wall. Structural breaks can also be achieved by mounting the inside and outside surfaces on separate sets of studs (staggered studs). The staggering adds to the total thickness of the wall.

- **Absorption in the Cavity**

  If the two outer layers of a wall have adequate weight and there is a vibration break between the inside and outer surfaces, the next most important factor is to have porous sound absorbing material in the study cavity. In most cases, exterior walls will be filled with thermal insulation which usually provides the required sound absorption. However, it is essential that the material in the cavity is porous; that is, material that one can blow air through. Various glass fiber and mineral fiver insulations are porous. Styrofoam and similar materials may be effective thermal insulators but are not sufficiently porous to serve as sound absorbing materials.



There are 5 key factors to creating a construction that is an effective barrier to sound. (1) the outer layers must be heavy, (2) there should be a vibration break between the two external surfaces, (3) porous absorbing material is needed in the cavity, (4) all cracks and holes must be sealed, and (5) there should be a large air space between the interior and exterior layers.

Figure B-1 Five Acoustic Variables to be Considered in Designing an Exterior Wall

- **Seal All Cracks**

  For a wall to be a high performance sound barrier, it is important to seal all cracks. Cracks around windows or doors could allow as much sound energy to enter the home as the entire wall surface of the house. For this reason, it is particularly important that windows and doors have effective enough seals to make the closed window or door as airtight as possible.

- **Large Spaces Between Layers**

  Small air spaces between layers of a sound barrier can seriously reduce the low frequency sound insulation. The combination of the weight of the two outer layers and the depth of the intervening air space creates a low frequency resonance. This low frequency resonance decreases the sound insulation of the construction at lower frequencies. This is a particular problem for typical thermal double glazing with two layers of glass separated by an air space of about 13 mm. Such windows are not very effective at reducing intruding aircraft noise. Similarly, multiple layers of gypsum board should not be installed with small air spaces between them. The required air space also depends on the weights of the layers but usually spaces of 100 mm (4 in) or more are required. Generally, it is better to avoid small air spaces between layers such as glass, gypsum board, and other types of sheeting.

Estimates of Noise Level Reduction

Examples of aircraft and vehicle noise level reduction (NLR) for various types of U.S. construction are given in Table B-1 which is reproduced from the Tri-Services Noise Planning Manual (U.S. Army Technical Manual 5-803-2, Planning in the Noise Environment, 1978). Although this material is somewhat dated, Table B-1 demonstrates the relationship between mass and attenuation. Table B-2 is reproduced from the Canadian document and the estimates of aircraft noise reduction were calculated for outdoor commercial jet aircraft and a typical Canadian living room. Tables B-1 and B-2 present the same basic information in slightly different format. Because thermal insulation contributes to acoustic insulation, the NLR for a Canadian house would be expected to be more like a house in the northern U.S. than in the southern U.S. For the more southern houses, the aforementioned Wyle Laboratory research report would be expected to give more realistic estimates.

TYPE OF CONSTRUCTION	NLR in dB
	AIRCRAFT AND VEHICULAR NOISE
Conventional wood frame – windows open	15-20
Conventional wood frame – windows closed	25-30
Conventional wood frame – no windows, or ¼” glass windows, sealed in place	30-35
1/8” glass windows, sealed in place*	20-25
1/4 “ glass windows, sealed in place*	25-30
Walls and roof – weighing 20 to 40 lbs/sq ft, no windows*	35-40
Walls and roof – weighting 40 to 80 lbs/sq ft., no windows	40-45
Heavy walls and roof – weighing over 80 lbs/sq ft., no windows*	45-50

*Assuming a surface area consisting of only this element

Table B-1 Typical Building Construction Noise Level Reduction (NLR) Values (U.S. Army, 1978)

Description of Construction	NLR in dB
Solid core exterior door with good seals	28
Single-glazed window (4 mm glass)	27
Thermal double glazing (4 mm glass, 13 mm air space, 4 mm glass)	27
Superior window (4 mm glass, 100 mm air space, 4 mm glass)	32
Recording studio window (6 mm glass, 100 mm air space, 6 mm glass)	36
Wood stud wall with wood siding on the exterior and gypsum board on interior	30
Wood stud wall with wood siding on the exterior and gypsum board on resilient channels on the interior	37
Wood stud wall with 22 mm(7/8th inch) stucco on the exterior and gypsum board on the interior	39
Wood stud wall with 22 mm(7/8th inch) stucco on the exterior and gypsum board on resilient channels on the interior	46
Wood stud wall with brick exterior and gypsum board on the interior	46
Flat roof or cathedral ceiling with single layer of gypsum board on the interior (without resilient channels)	25
Flat roof or cathedral ceiling with single layer of gypsum board on the interior on resilient channels	36
Flat roof or cathedral ceiling with double layer of gypsum board on the interior on resilient channels	39
Sloped roof with attic space that includes thermal insulation with a single layer of gypsum board on the ceiling mounted in resilient channels	43

Table B-2 Estimated Reduction of A-Weighted Aircraft Noise by Equal Areas of Various Building Façade Elements

The estimates of NLR for windows provided in Tables B-1 and B-2 assume that the aircraft noise comes from jet aircraft. But for the Army's most common aircraft, the helicopter, windows will not provide the same NLR as for a jet. As demonstrated by a comparison of Figures B-2 and B-3, the spectrum of a helicopter has a relatively lower frequency sound than the spectrum of a jet aircraft.

Windows provide more reduction of middle and high frequency sound than they do for low frequency sound, so a window transmits relatively more of the acoustic signature from a helicopter than from a jet. Figure B-4, which is reproduced from the 25 January 2001 Draft Final, City and Borough of Juneau, Flightseeing Noise Assessment, is an example of NLR for a helicopter. It presents the outdoor and indoor measurements for a residence with three large picture windows (one looking in each direction). Because of the Alaskan climate, all of the windows were double-paned which, according to Table B-2, should give about 27 dB NLR. In Figure B-4, the NLR averages out to 22 dB.

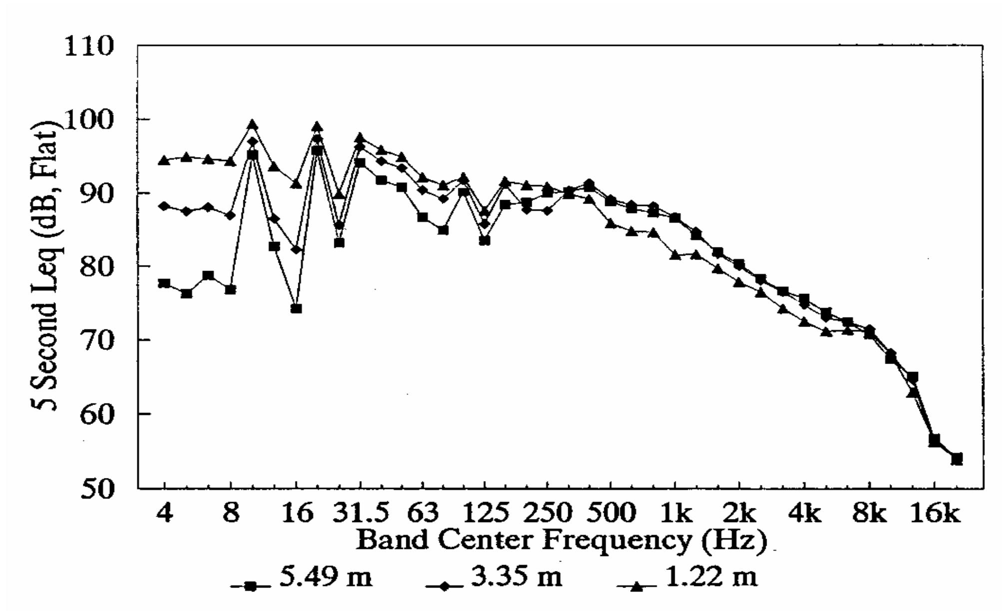


Figure B-2 Spectrum of Helicopter

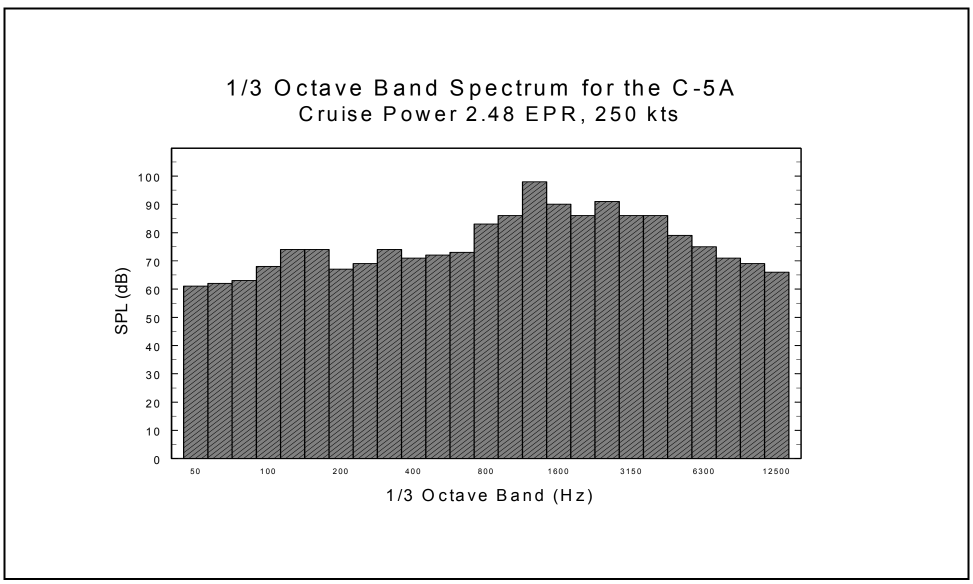


Figure B-3 Spectrum of Jet Transport

When a window has the potential to rattle, such as an old double-hung wooden sash window, the low frequency components of the helicopter acoustic signature can result in a further amplification of annoyance. A sound accompanied by rattle is, not surprisingly, more annoying than an equally loud sound without a rattle. This phenomenon was demonstrated with the UH-1H helicopter in a 1985 study conducted by the U.S. Army Construction Engineering Research Laboratory (CERL) (P.D. Schomer and R.D. Neathammer, The Role of

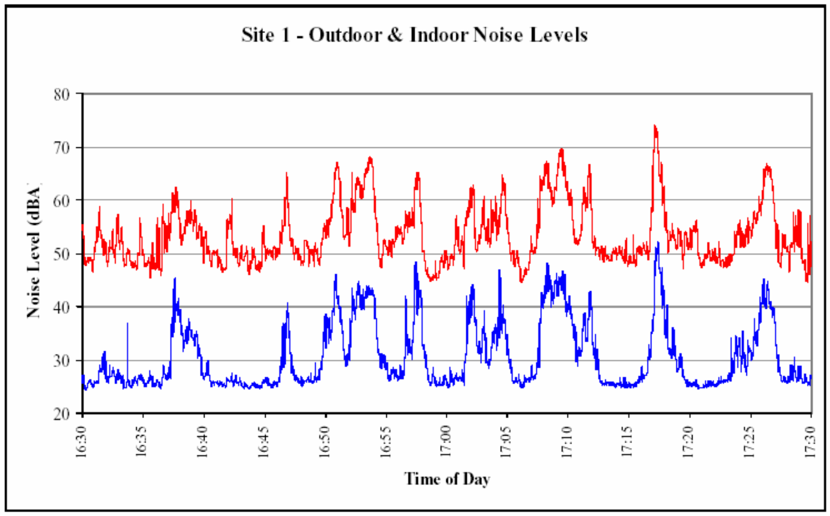


Figure B-4 Example of the Effectiveness of Thermal Pane Picture Windows for Attenuating Helicopter Noise

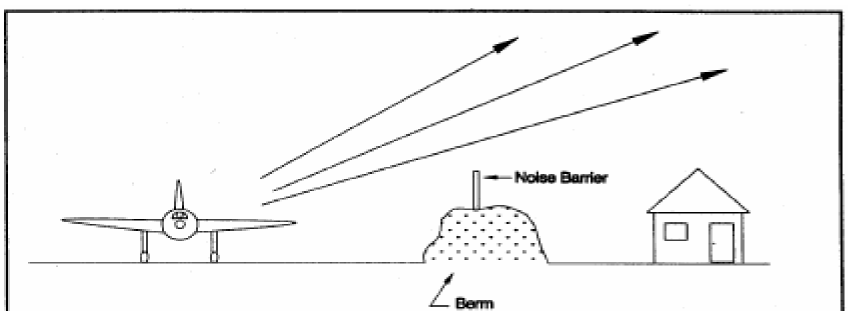
Vibration and Rattle in Human Response to Helicopter Noise). These researchers put subjects into an old wood-frame farmhouse and had them judge the annoyance of helicopter fly bys. After each fly by, the subjects were asked to compare the annoyance of the aircraft sound with a control sound. Independently, the attending technician kept a log of whether the fly by was accompanied by no rattle, a little rattle or a lot of rattle. When there was no rattle, the subjects rated the fly by as equally annoying to a same decibel control sound. When there was a little rattle, the control sound had to be 12 dB higher than the fly by sound to be judged as equally annoying. When there was a lot of rattle, the control sound had to be more than 20 dB higher to be judged as equally annoying to the fly by.

B.3 ORIENTATION OF THE HOME AND SITE PLANNING

Fixed wing aircraft noise is most intense immediately under aircraft flight paths. Consequently, it is possible to avoid the more intense fixed wing aircraft noise exposure by locating new homes a little farther from the aircraft flight tracks. But for helicopters, there is considerable horizontal propagation from the main rotor blades, and the propagation is more difficult to predict. For instance, a home on a hill near a helicopter flight corridor may be ideally positioned to receive helicopter flight noise compared with a home sitting at a lower elevation.

For both fixed and rotary wing aircraft near the approach or departure tracks of an airfield, it may also be possible to adjust the orientation of homes at a site so that noise sensitive areas are shielded from the aircraft noise. This is especially true when the aircraft flight tracks are not directly overhead but are to one side of the house. The appropriate orientation could create a patio or other outdoor use area in the acoustical shadow of the home.

In some situations, there may be considerable noise from aircraft on the ground from run-up or maintenance operations. Proximal features such as berms, unmanned accessory structures, dedicated barriers, and depressions can be effective shielding tools to attenuate noise and should be utilized in building location whenever possible. It is important that noise barriers be as close as possible to either the noise source or to the home where the noise reduction is required. They must be high enough or deep enough (when building in a depression) to block or avoid the direct line of site to the noise source in order to create an acoustical shadow in the area where noise reduction is required. As demonstrated in another study from CERL, interposing a hanger between helipads and the community can result in significant reduction of run-up noise (L. Pater and R. Yousefi, “Hangers as noise barriers for helicopter noise,” paper given at Noise-Con 93). Figure B-5, reproduced from the Canadian guidelines, illustrates the use of barriers at airfields.



When disturbing noise comes from aircraft on the ground, berms and noise barriers can be constructed to block the direct path of the sound. They are most effective if they are located either close to the noise source or close to the home.

Figure B-5 Use of Barriers with Noise of Airfield Ground Operations

B.4 PLANNING AND THE LAYOUT OF ROOMS IN THE HOME

An important principle for construction near highways and railroads also applies to construction near an airfield. If the noise is always coming from one direction, noise sensitive uses should be located on the quiet side of the building. The Canadian guidelines recommend that the noisy side have smaller windows than the quiet side. Doors should also be located on the quiet side along with any ventilation openings. The principle is illustrated in Figure B-6.

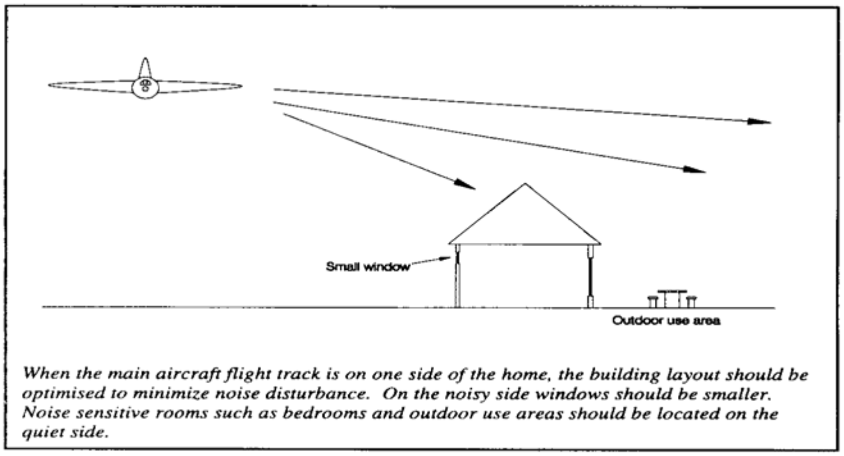


Figure B-6 Flight Corridor Location of Noise-Sensitive Uses Away from Source

B.5 WALLS

Table B-2 lists the NLR of five different Canadian designs for exterior wood stud walls. The NLR ranges from 30 to 46 dB and these estimates are in line with the estimates in Wyle Research Report WR 89-7. Table 3-4 of the Wyle document lists the Exterior Wall Rating (EWR) of a wall with aluminum or wood siding as 37 dB, or the same as the Canadian estimate. The Wyle Laboratory estimate for other wall designs is slightly higher than the Canadian estimates. As a note, the Wyle Laboratory estimates 49 dB for hollow concrete block and 58 dB for solid.

As pointed out by the authors of the Wyle Research Report, "windows and doors have overwhelmingly proven to be the deciding factors in home sound insulation." Past studies have shown that the noise reduction of dwellings lies generally in the range of 18 to 27 dB depending on the type of windows and doors.

B.6 WINDOWS

The Canadian guidelines in Table B-2 show the NLR for four window designs with a range of 27 to 36 dB NLR. European windows capable of attenuating by as much as 50 dB are now commercially-available in the U.S. As pointed out in the Canadian guidelines, there is a tradeoff between the attenuation afforded by the exterior wall and the windows. This tradeoff is illustrated by Figure B-7:

"The window is 1 m^2 in area and the remainder of the wall is 11 m^2. The window by itself would reduce the aircraft noise by 30 dB and the wall by 50 dB. The combined effect of the wall and the window, taking into account their different areas and different noise

reductions would be to reduce aircraft noise by 40 dB. If the window were reduced to 0.5 m^2, the combined noise reduction would increase to 43 dB. However, if the window were increased in area to 2 m^2, the combined sound insulation would be only 37 dB. The total sound insulation is largely determined by the weakest link".

The Canadian guidelines caution against trying to achieve greater attenuation by triple glazing and the use of special gases in the air space between two glass panes. The Canadian guidelines conclude, "The small improvements that result from these more complex constructions may be no better than would result from small increases in the weight of the glass or the air space between the glass."

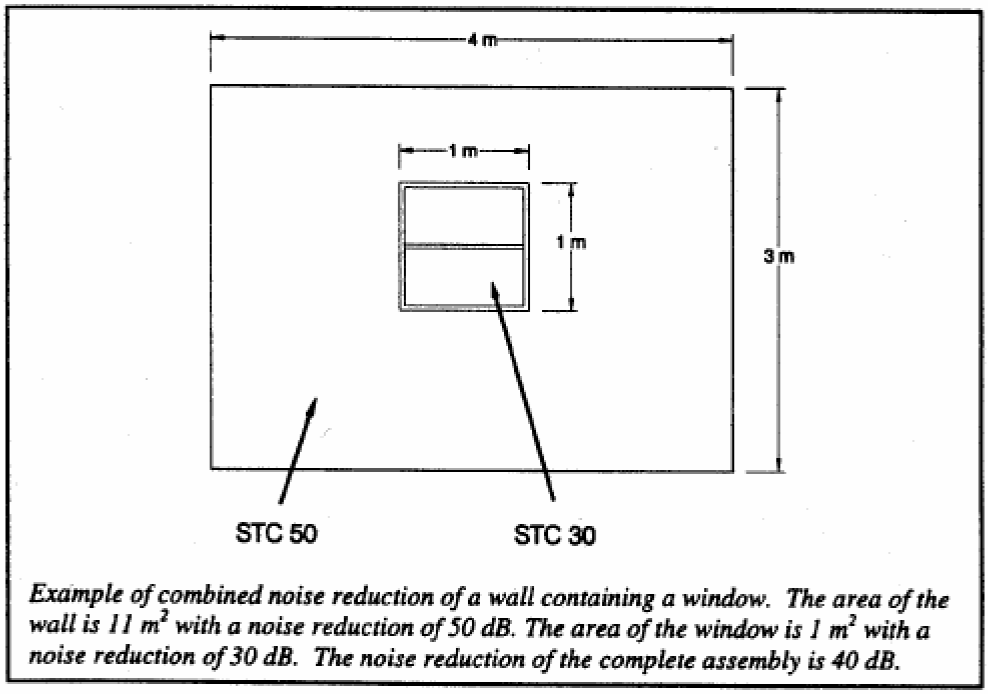
The Canadian guidelines also demonstrate the importance of non-opening windows for reduction of annoyance from helicopter noise. The left side of Figure B-8 shows the various points where the type of window used in Schomer and Neathammer's study is subject to leakage and vibration. The right side shows a non-vibrating and non-opening window.

B.7 DOORS

The authors of the Wyle report also noted that "the noise reduction for rooms with an exterior door is 4 to 6 dB less than that for rooms without a door." The Canadian guidelines state, "Even very good seals will probably degrade with continued use." According to the Canadian report, "Two practical ways to achieve improved sound insulation for doors are to use either double doors or an entrance vestibule. Two well sealed solid core doors with a 200 mm (8 inch) air space between them are expected to be more than 10 dB better than a single door. Including a small entrance vestibule is effectively a double door with a very large air space between the two doors and should also be very effective."

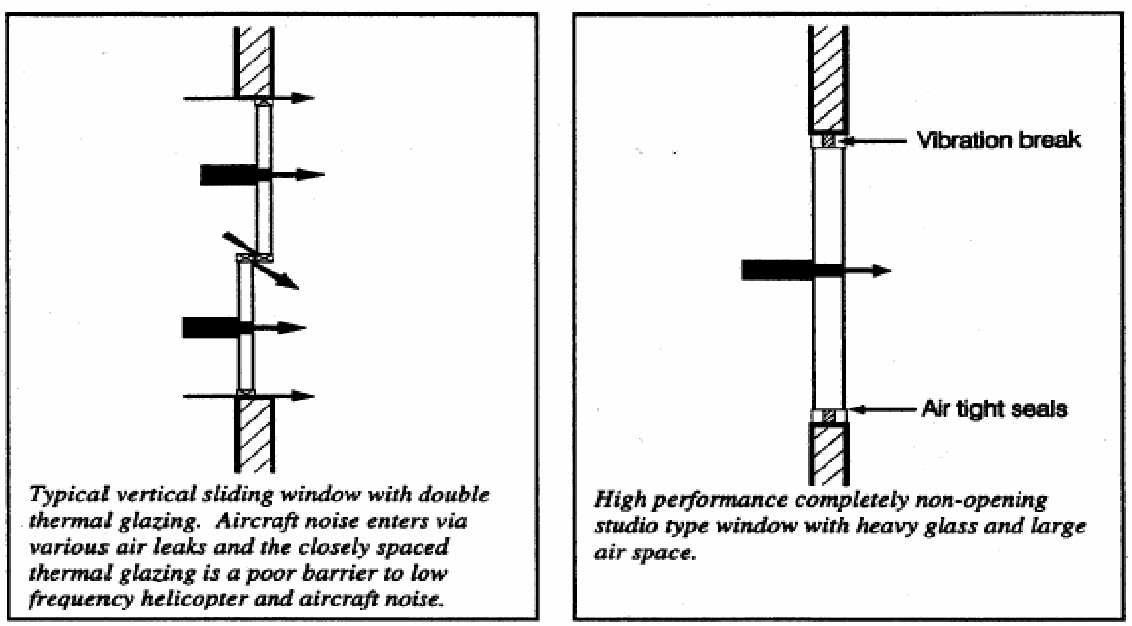
B.8 THE ROOF

Table B-2 lists a range of 25 to 43 dB NLR for roofs. Because of the popularity of "cathedral ceilings" in new residential construction, the author demonstrates how the typically poor NLR of this residential style can be improved. Traditional sloped roofs with attics start out as better acoustic attenuators than cathedral ceilings. With the addition of gypsum board on resilient channel and porous absorbing material in the air space, the NLR of the roof/ceiling combination climbs to 43 dB. The NLR can be undermined, though, by sound coming through an attic vent. Figure B-9 shows the Canadian recommendation for reducing that variety of sound infiltration.



Example of combined noise reduction of a wall containing a window. The area of the wall is 11 m^2 with a noise reduction of 50 dB. The area of the window is 1 m^2 with a noise reduction of 30 dB. The noise reduction of the complete assembly is 40 dB.

Figure B-7 Canadian Example of the Tradeoff between the NLR from a Window and an Exterior Wall



Typical vertical sliding window with double thermal glazing. Aircraft noise enters via various air leaks and the closely spaced thermal glazing is a poor barrier to low frequency helicopter and aircraft noise.

High performance completely non-opening studio type window with heavy glass and large air space.

Figure B-8 Effectiveness of an Opening as Compared with a Non-Opening Window

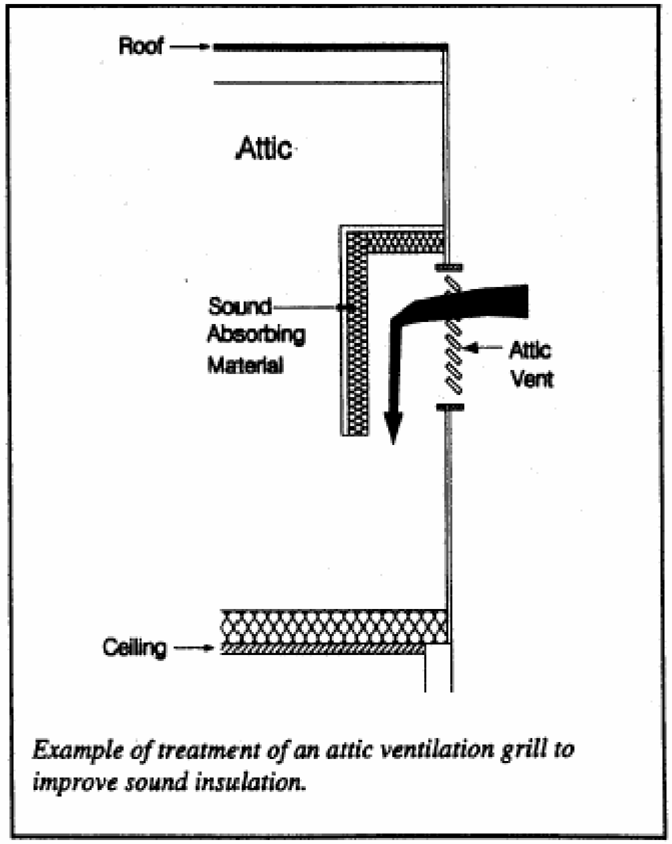


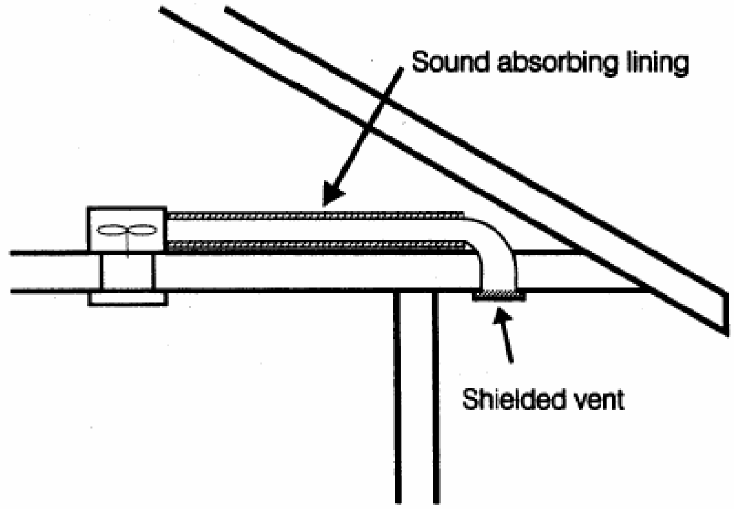
Figure B-9 Example of Treatment of an Attic Ventilation Grill to Improve Sound Insulation

B.9 CHIMNEYS, VENTS, AND OTHER OPENINGS

Cracks and leaks can be sealed, but vents are unavoidable. The best that can be done is:

- Locate bathroom and kitchen exhausts on the quiet side of the building.
- Locate vents in the soffit surfaces under the eaves to avoid a direct line-of-sight between the aircraft and the opening.
- Use ventilation ducts with sound absorbing linings
- Vent through an acoustic labyrinth (as shown in Figure B-10 from the Canadian Report).

Conventional open fireplace chimneys are less of an issue in the U.S. than in Canada but in either case the best that can be done is closing the damper when not in use.



Improving the sound insulation associated with a bathroom exhaust fan by locating the vent under the eaves where it is shielded from aircraft noise and by using ducts that are lined with sound absorbing material to reduce noise transmission.

Figure B-10 Example of an Acoustic Labyrinth

B.10 CONCLUSION

As stated previously, with the appropriate construction and orientation of the building, outside noise can be significantly reduced inside a structure.

Proximal features such as berms, unmanned accessory structures, dedicated barriers, and depressions can be effective shielding tools to attenuate noise and should be utilized in building location whenever possible.

Additionally, placement of ventilation ducts, wall openings, "dead" air space between walls, balconies, recesses, overhangs, and landscaping/vegetation should also be considered at the building design stage.

Furthermore, the actual construction materials can also play a role in the attenuation of sound. Increasing the mass of the materials used to construct roofs, walls, and windows will reduce sound infiltration and using heavy drapes, carpet, doors, and ceiling treatments will impede sound travel once it is inside the building

Summing up, the NLR of a structure can be increased by:

- **WALLS.** The NLR of walls can be increased by increasing the mass of the walls, using "dead" air spaces (increasing air space between walls), using staggered studs, sealing cracks and edges, using or increasing insulation, and using acoustic coatings. Also, special attention should be given to openings (electrical outlets, medicine cabinets, etc.) and the use of resilient materials to hold panels to studs.

- **ROOFS.** The NLR of roofs can be increased by increasing the mass of the roof and sealing cracks and edges.

- **CEILINGS.** The NLR of ceilings can be increased by using or increasing insulation, using acoustic coatings or ceilings, and using non-fixed suspension methods.

- **FLOORS.** The NLR of floors can be increased by increasing the mass of the floor, blocking off all joists, and using resilient supports between joists and floor.

- **WINDOWS.** The NLR of windows can be increased by using sealed windows, increasing glass thickness, using double glazed windows, and increasing the volume of "dead" air space in double glazed windows.

- **DOORS.** The NLR of doors can be increased by using solid core doors and using doorframe gaskets.

- **INTERIOR DESIGN.** The NLR of interior spaces can be increased by using heavy drapes and carpets, and using acoustic ceiling treatment.

Also, in addition to the NLR measures suggested above, the annoyance of low frequency noise can be further reduced by avoiding to the greatest extent possible the use of windows, doors, and other architectural features prone to rattle.

A list of “dos” and “don’ts” is published in an Army Construction Engineering Research Laboratory report, **Expedient Methods for Rattle-Proofing Certain Housing Components** (U.S. Army, 1987). Copies of this report should be made available to anyone wishing to build in the vicinity of a military installation.

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APPENDIX C

SOUND INSULATING HOMES AGAINST HIGH INTENSITY IMPULSIVE NOISE

C.1 INTRODUCTION

The guidelines for sound insulating homes against aircraft noise discussed in Appendix B do not apply directly to sound insulating against high intensity impulsive noise, such as sonic booms and the blasts from large guns. Whereas the objective with aircraft noise is to reduce the amount of sound getting into the house, the objective with blast noise is to reduce sound-induced house vibration. The importance of vibration is underscored by Figure C-1. Figure C-1 is a companion graph to Figure A-2 in the Appendix on Noise Complaint Guidelines. Whereas Figure A-2 shows the average peak **noise** level of blasts assigned to different annoyance categories by complainants listening in their own home, Figure C-1 shows the average peak window **vibration** of blasts assigned to the different annoyance categories. Comparison of these two figures shows that it doesn't matter whether people are judging peak window vibration or peak sound pressure level. For high intensity impulsive sound, the annoyance is due to vibration.

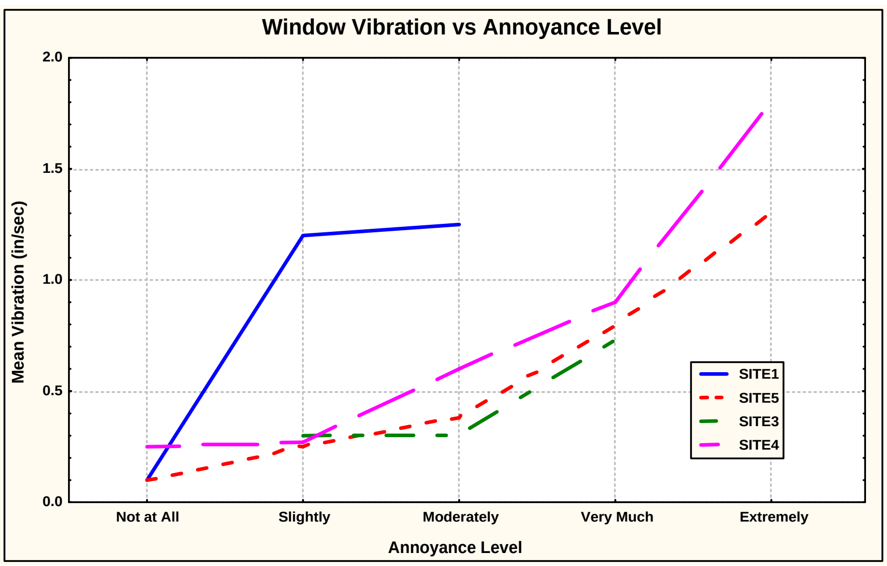

Figure C-1 Average Peak Vibration Level of Blasts Assigned to Different Annoyance Categories (by Complainants Listening to Blasts in Their Own Homes)

A typically type of closed structure (e.g., wooden building) was found to attenuate a peak level of more than 10 dB and exposure level of more than 5 dB. Open structures or barriers were less effective, usually less than 5 dB in peak level attenuation and therefore they have limited effect in noise control because attenuation of more than 20 dB is often needed (Paakkonen 1995). For noise control purposes, noise exposure is best reduced by solid, heavy thick and tight structures.

C.2 BLAST SPECTRUM

Figure C-2 shows the spectrum of a blast from a 120 mm gun. Unlike the spectrum of the C5-A jet aircraft shown as Figure B-2 in Appendix B, the gun blast spectrum is dominated by low frequencies. For the C5-A aircraft, the one-third octave band with the most energy is at 1,200 Hz. For the 120 mm gun, most of the energy is in bands below 50 Hz.

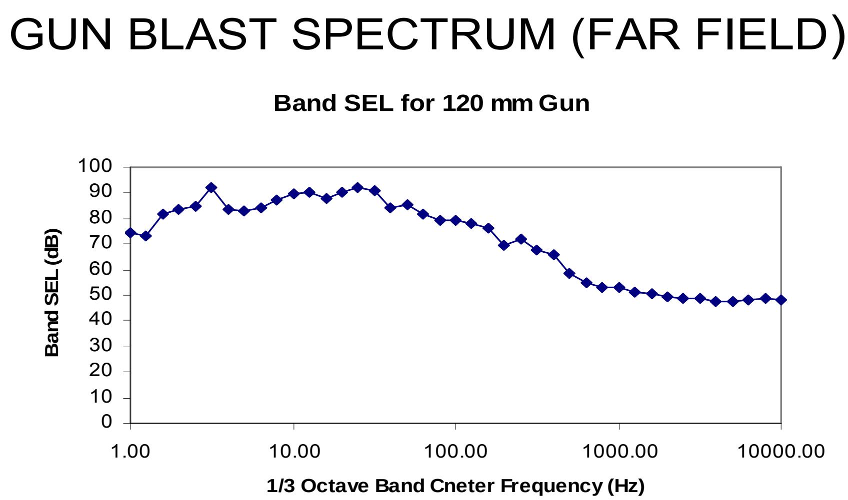

Figure C-2 1/3 Octave Band Spectrum of a 120 mm Tank Gun

Typical U.S. houses are not effective in attenuating low frequencies. According to Hubbard and Shepherd (1991), the outdoor-to-indoor noise level reduction (NLR) for a typical house with closed windows is less than 3 decibels for sound at 10 Hz. Above 10 Hz, the NLR increases by about 6 dB per doubling of frequency.

C.3 VULNERABILITY TO VIBRATION

According to Hubbard (1982), people in houses exposed to low frequency sound are most likely to detect vibrations in the windows and least likely to detect vibrations in the floor. This is shown graphically in Figure C-3, which is reproduced from Hubbard's 1982 review.

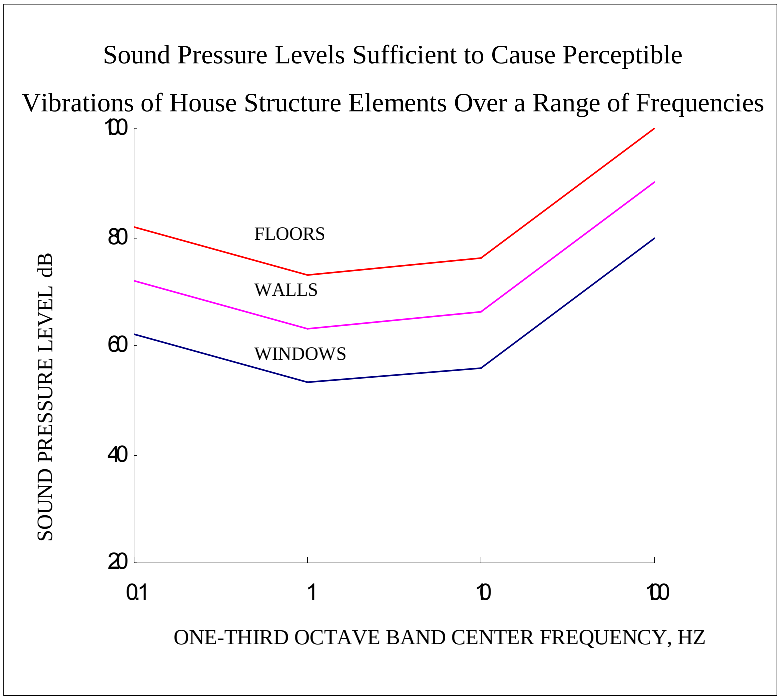

Figure C-3 Human Detection of Vibration for Different House Structure Elements and Sound Frequencies (Hubbard, 1982)

C.4 IMPORTANCE OF CONTROLLING HOUSE VIBRATION

A number of researchers have shown that intrusive sound accompanied by vibration is much more annoying than the same decibel level of intrusive sound without vibration. In Japan, Sato (1994) found that a 10 decibel increase in the vibration associated with traffic or railroad noise had the same effect on annoyance as increasing the 24 hour LEQ by 3.5 dBA. In a more controlled German laboratory study, Paulsen and Kastka (1995) demonstrated that the presence of vibration from a railway amplified the annoyance associated with sound levels between 30 and 60 dBA. In Sweden, Öhrström (1997) concluded that when homes are simultaneously exposed to railroad noise and vibration, mitigation of the vibration or a longer distance between houses and the railway line is needed, corresponding to a 10 dBA lower noise level than in areas without vibration. Schomer and Neathammer (1987) demonstrated that when the sound of a passing helicopter was accompanied by rattle, the annoyance increased by over 10 dBA. Working with simulated blasts, Schomer and Averbuch (1989) found that the contribution of rattle to annoyance depended on the sound level of the intrusive sound. With an outdoor blast level of 112 dBP, the presence of rattle added an effective 13 dB to the annoyance, whereas with an outdoor blast level of 122 dBP, rattle added an effective 6 dB to annoyance.

C.5 CONTROLLING WINDOW VIBRATION

Since people exposed to low frequency sound sources and blasts are likely to detect vibration of windows at lower sound levels than they detect vibration of walls and floors, the least expensive way to reduce annoyance is to reduce window vibration. Information on rattle-prone architectural features is available in a report authored by Schomer *et al.* (1987). The following list of desirable and undesirable window features in a low frequency noise environment has been reproduced from that report.

Windows: There are seven basic types of windows: fixed, casement, awning, sliding, double-hung, jalousie, and pivoting.

DO Use a fixed window if outdoor air is not required.

DO Use a casement or awning window which can be secured firmly against gasket.

DO Use gasket material liberally to reduce the gap between the sash and track and to soften the impact when these two components make contact. A second advantage is the improved reduction in heat loss.

DO Encase the double-hung window sash weights in a soft plastic jacket to soften the contact when the weight vibrates.

DO Apply a small felt disk to the lower edge of each jalousie window element to prevent a window to window contact. Manufacturers should bond a soft plastic sleeve to the window edge to prevent heat loss and rattle.

DON'T Allow the jalousie window opening mechanism to become loose and worn. All shafts should rotate in soft plastic bushings. All gear clearances should be minimized. Linkage should be encased in soft plastic sleeves.

DON'T Allow the window hardware to loosen. Inspect the hardware periodically, and apply preventive maintenance.

DON'T Use a sliding, double-hung, jalousie, or pivoting window as a new or replacement window due to the gaps which exist between the sash and track.

A proof-of-concept was published by Schomer *et al.* (1991). Working with the solid masonry construction of German houses, these researchers were able to achieve a 14 dB improvement in community response by adding a second pane to the windows separated with a small air gap.

C.6 CONTROLLING DOOR VIBRATION

Figure C-3 does not show the threshold for detecting door vibration. Presumably, doors are less likely to vibrate than windows. Evidence that door vibration can be important for annoyance comes from a paper by Ochiai and Yamashita (1989). They studied the annoyance associated with the rattling of Japanese style sliding doors. They found that the most effective method of reducing rattle was fixing the doors to the frame by rubber packing.

The engineers who wrote the CERL manual on rattle-proofing assumed that door vibration is important. They made the following recommendations about doors:

Doors: Doors operate by: swinging, bypass sliding, surface sliding, pocket sliding, and side-hinge folding. There are flush, paneled, French, glass sash, jalousie, louvered, shuttered, screen and Dutch doors.

DO Use swinging paneled doors for the home exterior. Swinging and side-hinged folding doors should be used in the home.

DO Use a single- rather than a multiple-element garage door. Weather strip the building jamb and allow minimum clearance between the overhead track and the roller. Encase the springs in soft plastic jackets.

DO Avoid French, Dutch, jalousie, louvered, and shutter doors. If used, separate the door elements using soft plastic foam or weather stripping-type materials.

DO Use a plastic screen instead of a metal screen.

DO Insure that the door hardware is in good repair. Minimize the gaps in lockset tongues where the tongue fits into the jamb. Insure that hinge pints are tight and coated with plastic. Place a soft plastic foam or felt strip on door mail slots to prevent hard contact.

DON'T Use lightly constructed screen doors. Enclose the safety chain in a soft plastic sleeve and insure that the hardware is tight and in good repair.

DON'T Use sliding doors, particularly the pocket sliding type. If sliding doors must be used, do not hang the door loosely from the ceiling but use a bottom track also. The gap between the track and the door should be minimized. A track liner of soft plastic or weather stripping-like material will minimize contact.

C.7 CONTROLLING WALL VIBRATION

Figure C-3 shows people being more sensitive to wall vibration than floor vibration. Obviously, if a wall has enough mass, such as in a masonry structure or even an environmentally-friendly straw bale house, low frequency sound cannot induce vibrations. The acoustical engineers who wrote the CERL rattle-proofing manual didn't address walls, because adding mass to exterior walls is usually too expensive to be considered. The mass of the wall should be considered before construction, not after. Instead of recommending increased wall mass, the CERL engineers suggested ways of isolating various architectural features from vibrating walls.

DO Install soft plastic foam or weather stripping-like material to the lower edge of the back of the hanging mirrors and picture frames to prevent direct contact by the frame or mirror with the wall.

DO Separate small items placed on shelves, in closets, or on other horizontal surfaces from these surfaces by using small felt or foam disks or strips glued to the underside of the item.

DO Separate plates placed horizontally on shelves using soft plastic foam doilies.

DO Insure that window air-conditioners are installed properly. The refrigeration coils should be separated. Air intake and exhaust louvers should be separated by foam strips or disks.

DO Keep downspouts and gutters in good repair. Insure that all seams are tight and covered with duct tape.

DON'T Allow home heating ducts and registers to loosen. Use duct tape around all seams

C.8 CONTROLLING CEILING VIBRATION

The acoustical engineers who wrote the CERL rattle-proofing manual concluded that some types of ceilings can be susceptible to rattles. They made the following recommendations:

DO Insure that enclosed lighting fixtures are well made with minimum gaps. Insure that the sheet metal housing is stiff and well secured at its contact points.

DON'T Use a dropped acoustical tile ceiling. If one is used, insure that contact between vertical wires and joist and metal frame is eliminated.

DON'T Use light fixtures that hang from the ceiling by a chain or similar device. Also, avoid light fixtures with loose elements.

Even in houses with walls of sufficient mass to resist sound-induced vibration, hanging objects can vibrate if there is a low frequency resonance inside the room. For example, an individual whose well-constructed home is located across the Chesapeake Bay from Aberdeen Proving Ground firing ranges reported that blasts were shaking Christmas tree ornaments during a holiday party. Another neighbor reported watching a book move across the face of a vibrating table. In these cases, low frequency sound was entering the room through large picture windows. This phenomenon is known as Helmholtz resonance, and it has been studied in detail by Hubbard and Shepherd (1991). These researchers wrote,

"*Depending on the measurement locations, the configurations of the interior spaces and whether the windows are open or closed, it is possible to observe higher levels inside than outside. This phenomenon most often occurs at low frequencies which coincide with room modes or Helmholtz resonances. Helmholtz resonators are formed by room volumes in combination with openings due to windows and doors. The transmitted noise is affected by the mass and stiffness characteristics of the structure and its dynamic responses, and the dimensions and layouts of the rooms. Minimum noise reductions occur at frequencies near 10 Hz, probably because of associated major house structural resonances." "Noises in this low-frequency range will probably not be heard by human observers but may be observed indirectly as a result of noise induced vibrations of the building structure and furnishings."*

C.9 CONTROLLING FLOOR VIBRATION

If a room is behaving as a Helmholtz resonator, then the floors are prone to vibration. Floor vibration is not addressed in the CERL manual, because there are no inexpensive and easy fixes to floor vibration. Fortunately, people are least likely to experience floor vibration, and people who complain about disturbance from Army guns rarely mention floor vibration. There have, however, been claims of mobile homes being moved from their foundation. As with any other structure, mobile homes can become Helmholtz resonators, and the floor would be expected to be as susceptible to vibration as the walls.

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APPENDIX D

LAND USE PLANNING AND CONTROL TECHNIQUES

D.1 GENERAL (U.S. Army 1988)

Several different planning and land-use control techniques are normally available to local governments to prevent noise intrusions. Controls that are generally most useful for achieving compatibility zoning, easements and development rights, and land purchase are discussed in this appendix. Other controls such as building codes (noise insulation requirements), health and housing codes, programming of public capital improvements, and cooperation of financial institutions have either less or specialized applicability.

D.2 ZONING

The most common and useful land-use control method is zoning. This method is an exercise of the police powers of state and local governments that designates the uses permitted on each parcel of land. It normally consists of a zoning ordinance that delineates the various use districts and includes a zoning map based on the land-use element of the community's comprehensive general plan. At the same time, a zone is subject to change and must be monitored continually if it is to remain a viable compatibility tool.

- **Uses of Zoning.** Zoning should be applied fairly and based on a comprehensive plan. Zoning ordinances implement provisions of the comprehensive plan. This plan must consider the total needs of the community along with specific needs of the installation. For example, to zone a parcel of land for industrial or warehouse usage simply because it lies within a noise impact area is not acceptable. Such an action could be considered "arbitrary, capricious, or unreasonable" and thus vulnerable in the event of judicial review. The plan must clearly demonstrate that there is a reasonable present or future need for such usage. Zoning can and should be used constructively to increase the value and productivity of land within the noise areas. Used within its limitations, zoning is the preferred method of controlling land use in noise-impacted areas.

- **Limitations of Zoning.** Zoning has several limitations that must be considered when using it as a compatibility implementation tool. These limitations include:

Zoning is usually not retroactive. That is, changing a zone primarily for the purpose of prohibiting a use that already exists is normally not possible. However, if such zoning is accomplished, the use must be permitted to remain as a "nonconforming" element until the owner has had ample opportunity to recoup his/her investment.

Zoning is jurisdiction-limited. Installation impacts often span more than one zoning jurisdiction. In this case, zoning requires coordination of all involved jurisdictions. Zoning that implements a compatibility plan will often be composed of existing and new zoning districts within each of the zoning jurisdictions covered by the plan. Each jurisdiction is likely to have a different base zoning ordinance with districts having different applicability for implementing the compatibility plan. Counties in many states do not have zoning authority; hence, land-use control via zoning in these states stops at the municipal boundary.

Zoning is not permanent. In any jurisdiction, zoning can be changed by the current government body; it is not bound by prior zoning actions. Consequently, zoning that achieves compatibility is subject to continual pressure for change from both urban expansion and enterprises that might profit from such changes. When these changes are proposed, the environmental impacts may require assessment. Also, from time-to-time the entire zoning ordinance for a jurisdiction will be updated to accommodate increased growth or incorporate new land-use concepts.

Cumulative zoning can permit incompatible development. Several communities still have "cumulative" type zoning districts that permit all "higher" uses (such as residential) in "lower" use districts (such as commercial or industrial), thus supporting development that may be incompatible. In these instances, it is necessary to prepare and adopt new or additional zoning districts of the "exclusionary" type that clearly specify the uses permitted and exclude all others.

Zoning Board of Adjustments actions granting variances. Variances to the zoning district or exceptions (e.g., schools or churches) written into the zoning ordinance can also permit development that may be incompatible.

- **Positive Features of Zoning.** The zoning ordinance may be the most attractive land-use control to prevent development around installations. First, zoning is the most effective control because, by law, it can prohibit specific developments. Second, this technique normally costs the installation nothing.

- **Negative Features of Zoning.** The installation must rely on the municipality's governing body for proper zoning solutions. This may involve a political struggle beyond the installation's control. Also, the municipality must be wary of "taking land without just compensation," which is an issue often raised in zoning proceedings.

D.3 OVERLAY DISTRICTS

An overlay district is generally defined as any specially mapped district which is subject to supplementary regulations or requirements for development. Overlay districts, by either adding restrictions to or removing restrictions from the underlying zoning, provide specific provisions designed to address issues unique to a particular geographic area. They are used to curb discordant development in places where a specific resource (cultural, economic, or environmental) is in jeopardy.

The following are some examples of situations that may garner the creation of an overlay districts:

- Neighborhood/Historic Area Preservation
- Focused Economic Development – targeted revitalization areas, business parks, etc.
- Natural Resource Protection – watersheds, aquifers, wildlife corridors, etc.
- Infrastructure Protection – airports, military bases, ports, etc.
- Specific Plans – university districts, cultural districts, etc.

The provisions set forth in an overlay district can regulate any number of things from construction materials or styles (to better fit a historical district or provide for noise protection next to an airport), to business types and practices (in order to protect something like a reservoir).

- **Positive Features of Overlay Districts.** Allow great regulatory flexibility to be assigned to a very specific area so any inconvenience affects the fewest number of people possible. Also costs the local government and sponsoring party very little to implement.

- **Negative Features of Overlay Districts**. Must be approved by county/city council and is subject to public hearings. Implementation also subject to local political climate and public perception/attitudes.

D.4 EASEMENTS

Easements can be an effective and permanent form of land-use control. In many instances, they may be better than zoning for the installation's compatibility issues. Easements are permanent with the title held by the purchaser until sold or released, and work equally well within different jurisdictions. They are directly enforceable through civil courts and may often be acquired for a fraction of the cost of the land value. Another consideration is that the land is left free for full development with noise-compatible uses.

- **Definition.** An easement is a right of another to part of the total benefits of the real property owner. Ownership of property includes possession of a series of rights to the use of that property. Certain rights to the property are always retained by the state or the general public, i.e., police power, taxation, eminent domain, and escheat (right of the sovereign to own those properties not in the ownership of others). Other rights are retained by neighboring property owners (e.g., the flow of water across land). Rights of ownership, i.e., possession of all rights in the land except those retained by the state, general public or neighbors, may be bought and sold separately. When property is acquired, usually all rights are purchased (i.e., in fee simple). However, it is possible to buy only selected rights that are actually needed. These rights can be acquired in the form of easements, with the other rights retained by the owner. There are many types of easements. They can be categorized as subsurface easements such as pipelines and underground utilities; surface easements, such as roads, utilities, and access; and above-surface easements, such as air rights or navigation easements. The cost of an easement is determined by the value of those rights to the land owner. If the easement will not significantly impair the owner's contemplated usage or sale of the land, the cost should be low; but, if it does, the cost will be higher.

There are two basic classes of easements - positive and negative. In positive easements, the right to do something with the property (e.g., build a road, install power line, or create high levels of noise over the property) is acquired. In negative easements, the rights are acquired to prevent the use of the property by its owner for certain activities. These easements may include the owner's rights to erect billboards, cut timber, build above certain elevation, or perhaps use the land for any noise-sensitive use.

For noise compatibility issues, both the positive easement to make noise over the land and the negative easement to prevent the creation of an unprotected noise-sensitive use on the property may need to be acquired to ensure adequate control. The easement should give its owner the right to make noise over the property and it should also include purchase of all the property owner's rights to establish or maintain an unprotected noise-sensitive use on the property. In the case of an existing unprotected noise-sensitive use, the cost of the easement could include the cost of either soundproofing or removing the noise-sensitive use from the property. A specific list of noise-sensitive uses, based on the criteria used for the compatibility study, should be specified along with the sound attenuation (or other protection) sufficient to place the noise-sensitive uses within the sound environment specified by the criteria.

- **Obtaining Easements.** Easements can be obtained in several ways, including purchase, condemnation, and dedication. For each easement acquired, it is wise to consider including a legal description of the noise that may be created over the property and classes of uses that may be established or maintained with and without soundproofing.

Purchase: Easements can be purchased through negotiation with the price based on the value to the owner of the rights surrendered. Timing can have a significant effect on the price paid; once the subject land has come into the arena of speculation, prices tend to rise quickly. Under certain circumstances, Federal assistance may be available for such purchases.

Condemnation: Easements, as well as full rights to property, can also be obtained by condemnation. The cost, while still likely to be less than outright acquisition (fee simple), is likely to be significantly higher than similar rights obtained through negotiation. Also, the cost of any ill will generated by a condemnation action, while difficult to measure, can be significant.

Dedication: Dedication is another way to obtain easements. Two common types of dedication - subdivision and voluntary - are discussed briefly below.

Subdivision: Subdivision regulations governing the development of land for industrial or other purposes can include provision for dedicating private land or easements for public purposes. When easements for airport-environs compatibility are considered necessary and are determined to be compatible with the intended land use, the need for such easements should be a required consideration in the review and approval of subdivision dedications.

Voluntary: Land owners in un-zoned areas may sometimes be persuaded to dedicate easements voluntarily for compatibility over their undeveloped land if assured of a fixed location for noise-impact areas. Thus, when the land is eventually zoned, the easement will help assure the owner of obtaining a zoning classification compatible with the noise.

This arrangement may permit a lower tax rate during the interim years and may, coincidentally, generate a higher ultimate price for the land.

- **Positive Features of Easements.** Easement purchases are very straightforward transactions and are almost always less expensive than fee-simple purchases. They allow the installation to retain control over adjacent land without the burden of actual ownership. They are also usable in cases for which development already surrounds the installation.

- **Negative Features of Easements.** There may be difficulty in obtaining the necessary easements, particularly when many land owners are involved, because their cooperation is required. Unless otherwise specified, the rights are not automatically transferred upon a resale of the land, so further negotiations may be required.

D.5 TRANSFER OF DEVELOPMENT RIGHTS (TDR)

TDR involves separate ownership and use of various "rights" associated with a parcel of real estate. Under the TDR concept, some of the property's developmental rights are transferred to a remote location where they may be used to intensify allowable development. With TDR, for example, lands within an installation's noise-impacted area could be kept in open space or agricultural areas and their developmental rights for residential uses transferred to locations outside the area. Landowners could be compensated for the transferred rights by their sale at the new locations or the rights could be purchased by the Army. Depending on market conditions and/or legal requirements, the Army could either hold or resell the rights. The TDR approach must be fully coordinated with the community's planning and zoning office. It may be necessary for the zoning ordinance to be amended so that it permits TDRs. Also, transfers usually must be contained within single zoning jurisdictions.

- **Positive Features of TDRs.** The program would be inexpensive or cost-free to the installation since the local government would administer it. The program could also stimulate growth and development of the property to which developmental rights were being transferred.

- **Negative Features of TDRs.** One potential problem is record keeping. Because of the complexity of the transaction, it is often difficult to keep track of the principals and the exact number of rights that are sold and bought.

D.6 LAND PURCHASE

Fee-simple purchase of noise-impacted land is the most positive form of land-use control. It is also usually the most expensive. However, when combined with either resale for compatible uses or retention and use for a compatible public purpose, the net cost may be reduced greatly. As a preventive measure, purchase should usually be limited to critical locations or to cases for which other solutions would not work. Acquisition can be through negotiation with the property owner, by deed or gift, or through condemnation.

- **Positive Features of Land Purchase.** An obvious positive feature of this method is that it allows the installation to gain complete control over the use of surrounding land. Ownership also allows eventual sale of property. This installation program reduces initial expenditures by allowing the property to be acquired over time.

- **Negative Features of Land Purchase.** The biggest problem with this method is the initial cost of acquiring the land. This initial outlay may prove too expensive to justify the acquisition. In addition, the cost of maintaining the property may prove too expensive in the future. Development on the property still could be prevented by restrictive or sales agreements.

D.7 BUILDING CODES

A building code prescribes the basic requirements that regulate construction of structures. The building code is adopted by the local governing body to protect the health, safety, and general welfare of the occupants of these structures. The code establishes a set of requirements covering matters such as fire protection, building materials, lights, ventilation, exits, plumbing, and others. Although building codes are not a technique to actually prevent development, they can restrict it, especially near Army installations. A code can require that walls, partitions, and floor-ceiling construction have minimum sound transmission capabilities. The code can specify a certain sound transmission class (STC) that must be obtained. Specific construction techniques and materials can be stated in the code. Also, the code should require that certain noise levels are maintained after the structure is complete.

- **Positive Features of Building Codes.** The positive feature of the building code is that it promotes construction and development of structures that contain noise-proofing features.

- **Negative Features of Building Codes.** The negative feature of building codes is that they do not prevent or restrict any type of land use around installations.

D.8 SUBDIVISION REGULATION

Subdivision regulations are a means by which local government can ensure that proper lot layout, design, and improvements are included in new residential developments. These regulations specifically set guidelines that developers must follow when constructing their subdivisions; examples are minimum requirements for road widths, lot arrangements, allocation of facilities, the relationship of the subdivision to the surrounding area, and the dedication of property. Subdivision regulations are used to ensure that the health and habitability of each new residential development are maintained.

All local government subdivision regulations require some type of dedication of open space to the public. This provision could be structured such that the space is located nearest the Army installation. Noise barriers might also be erected along these buffer areas. Also, larger buffer areas could be required for subdivisions closer to the noise source.

- **Positive Features of Subdivision Regulations.** Subdivision regulations can be used effectively diminish noise levels in a residential area. This control can be achieved by carefully locating open spaces among units in the subdivision.

- **Negative Features of Subdivision Regulations.** Subdivision regulations alone will not prevent development around or near an installation. They are only a way to diminish the impact of noise emanating from the installation. Buffers placed in the subdivision may not be adequate to reduce the noise levels, providing only partial noise reduction. Administrative responsibility for subdivision regulations would then increase because of the additional requirements for noise attenuation. Thus, the cost to both the local government and the homeowner would increase.

D.9 HEALTH CODES

The health code in a given community sets up the requirements that protect residents from adverse elements that may endanger them. These elements include disease, poor sanitary facilities, and inadequate or unsafe water supplies. Requirements in the code encompass all types of land uses. Similar to the building code, the health code does not actually prevent development around Army installations. The codes, however, can protect people from the noise impact of a nearby installation. A standard can be built into the code that would apply to noise-sensitive uses such as homes. The developer would be required to prohibit excessive noise levels in the development or consider another use that is not noise-sensitive.

- **Positive Features of Health Codes.** The health code could be used in areas where zoning either is not used or is not an option. In most cases, the health code would be too strict to allow residential uses near installations, thus requiring some other, more compatible land use such as a manufacturing plant.

- **Negative Features of Health Codes.** The health code, depending on its complexity, is often difficult to administer. Also, the field checks (to ensure compliance) and substantial paperwork slow development

D.10 DISCLOSURE OF NOISE LEVELS

Noise levels in the community can be measured and recorded. By making these levels public information, incompatible uses around Army installations might be prevented. Noise levels can be disclosed in several ways. One method is by an ordinance or an amendment to an existing ordinance, which could be passed by the local governing body, requiring disclosure. Another method would be to implement a voluntary program among realtors in the community, who would inform the potential purchaser of any unacceptable noise levels. Colorado has a disclosure law which applies to noise. Maps generated by the Installation will be distributed through realtor associations and mailed to realtors in the region. The maps contain a detailed description of the noise environment surrounding the Installation and the Installation noise contours overlain on the surrounding communities. The maps will also contain a written explanation relating the noise contours to things that the reader understands. Furthermore, these maps will be provided to regional newspapers to be printed on a regular basis as full-page pull-outs.

There are several ways in which such a program can be applied at the local level. First, a statement of noise levels could be included in the deed so that the purchaser of the property knows about them. Second, real estate or leasing agents could be required to inform prospective purchasers or tenants about the potential noise problem. Also, the noise level for that area could be posted on any "for sale" or "for lease" sign placed on the property. Finally, noise contours could be published on all subdivision plots and possibly all municipal, land use, and zoning maps.

- **Positive Features of Disclosing Noise Levels.** The program would make information available to the public that had not been previously, including new residents who are unfamiliar with the area. The public could then make more informed choices about locating their residences and businesses.

- **Negative Features of Disclosing Noise Levels.** Simply disclosing the noise level information does not mean that the information will be used. Programs will be required to educate the public and ensure that the public remains informed in the future. Moreover, this measure could become costly and time-consuming if noise contours were required to be placed on all municipal maps.

D.11 HUD/VA REGULATIONS

Both the Department of Housing and Urban Development (HUD) and the Department of Veterans Affairs (VA) have regulations concerning noise levels in areas where they might help finance new construction. Both agencies follow the DOD guidelines concerning the ICUZ Program. Neither agency will make loans in areas identified as having unacceptable noise levels; that is, areas corresponding to a ADNL of 75 or greater (noise zone III). Only when the ADNL is less than 65 is a site totally acceptable. This control method has potential application to all DOD installations.

- **Positive Features of HUD/VA Regulations.** The program is similar to the development loan restriction except that public money is involved. Development, mostly residential, would be prohibited near an Army installation where noise levels are unacceptable.

- **Negative Features of HUD/VA Regulations.** These provisions do nothing for existing developments. Also, there is no current provision to prevent loans on the resale and subsequent purchase of existing structures. This measure is primarily limited to one type of land use - residential.

D.12 LAND BANKING

The term "land banking" is defined as a system in which a government acquires a substantial fraction of land in a region available for future development for the purpose of implementing a public land-use policy. Land banking prohibits the land being acquired from becoming committed to a specific use at the time of acquisition; in addition, the land must be large enough to have a substantial effect on urban growth patterns. Land banking differs from permanent acquisition in that it places the land in a temporary holding status to be turned over for development at a future date. Land banking can be used when development of a future installation is known. For example, land in excess of that required for the installation can be purchased and held for future use.

- **Positive Features of Land Banking.** The two primary arguments in favor of land banking are that it will have an anti-inflationary effect on land prices, thus preventing land speculation, and it will permit more rational patterns of development rather than urban sprawl.

- **Negative Features of Land Banking.** Positive aspects of land banking are disputed on the basis that if there is an orderly development of land, there will be no land that is "wasted". Therefore, the functional use of each parcel of land will increase, thus raising the price of that parcel. Another factor to consider is that the program may become politically manipulated. Government officials in charge of the program could show favoritism both when lands are acquired and opened for sale on the market. In addition, an expenditure may be too large to even begin a program of land banking. Proponents claim, however, that the money can be recovered once the site is developed.

D.13 SPECIAL TAX TREATMENT

Special or preferential tax assessment of land by a local government allows an owner of a piece of property to pay lower or no property tax. By taxing land around Army installations differently, open space can be maintained. There are three primary methods of using taxes to keep space open. First, tax exemption of open property could be encouraged. Second, preferential assessment of land would allow agricultural or open land to be taxed at a substantially lower rate. Third, tax deferral allows the owner of open property to forego property tax payments until a non-open space use is developed. Before such use is approved, however, all tax deferrals would have to be paid.

The States of Maryland and Pennsylvania have used preferential assessment in efforts to preserve open space and Virginia pioneered the tax deferral scheme. Both of these programs should be studied to determine their applicability to specific installations.

- **Positive Features of Special Tax Treatment.** These methods are, again, a way of preventing development at no cost to the

Army. The preservation of existing uses, especially agriculture, is promoted as well. Property that abuts the open space will become more valuable through the amenity that open space provides. The added value translates into increased tax revenue for the local government. Because the open space is adjacent to an Army installation, the value of the amenity is somewhat diminished, however. Even if the value of the abutting land uses stays constant, the tax program has worked.

- **Negative Features of Special Tax Treatment.** The cost of the program must be absorbed by the local government, which may refuse to implement it for this reason.

D.14 CAPITAL IMPROVEMENTS PROGRAM (CIP)

Capital improvements programming is the multi-year scheduling of physical upgrades to public property. A capital improvements program (CIP) is a planning tool used by local jurisdictions to phase the installation of needed public facilities (e.g., water and sewer, roads, schools) on a priority basis. A CIP usually projects needs three to six years into the future, specifying what public improvements will be constructed. Scheduling is based on studies of fiscal resources available and improvements needed. Many communities are starting growth management systems, of which a CIP is an important component. The CIP identifies the methods by which improvements will be financed and the source of the funds. Since development usually occurs where capital improvements are located, the extension of municipal services into an area makes that area more attractive to developers than sites without the improvements (i.e., the developer saves both time and money). Local governments should avoid extending capital improvements into high-noise areas to avoid the possibility of incompatible uses.

- **Positive Features of CIP.** There are many benefits to an effective CIP. The CIP can: ensure that plans for community facilities are completed; effectively schedule public improvements that require more than one year to construct; avoid improvement mismanagement; lead to effective growth management; and much more. CIP can and should be coordinated with local zoning ordinances to provide for growth management.

- **Negative Features of CIP.** Capital improvements are limited to expenditures for physical facilities with relatively long-term usefulness and permanence. Often, misuse of a CIP can lead to haphazard or unwanted development.

D.15 DEVELOPMENT LOAN RESTRICTIONS

To fund their projects, developers often need to borrow money from lending institutions. If their funds cannot be obtained, development will not occur. Restricting or prohibiting mortgage and/or other loans for certain land uses are thus a way to control development. For example, state and local governments could designate areas around Army installations for which loans to developers are prohibited. The designated areas would coincide with certain noise contours that would have already been determined. The local government would then prohibit banks and other lenders from making development funds available for those areas.

- **Positive Features of Development Loan Restrictions.** The attractive feature of this program is that it costs nothing for the local government to implement and still prevents development effectively.

- **Negative Features of Development Loan Restrictions.** The program usually cannot be implemented immediately because of possible court litigation. It is likely that lending institutions will sue the local government for not allowing them to use their money as they see fit (i.e., making loans to developers).

D.16 PUBLIC/PRIVATE LEASEBACK

Leaseback is a financial arrangement in which the land is acquired and controlled, but not necessarily occupied, by the owner. This method can be used by both the public and private sectors. The leaseback arrangement in the private sector requires two simultaneous steps. First, an investor purchases real estate owned and used by a business firm or government. Second, the property is leased back to the firm or government by private persons for specific uses in accordance with the approved plan for the area. Customarily, the term of the lease ranges from 20 to 40 years.

- **Positive Features of Public/Private Leaseback.** Leaseback offers a way for public agencies to acquire land, yet provide for the continued use of the land by others. Public agencies can thus limit the land use, while acquiring some income from the property. The leaseback method is popular in the private sector because it provides capital from outside sources and is a flexible form of financing.

- **Negative Features of Public/Private Leaseback.** Public agencies often have the usual landlord's management problems. The leaseback arrangement also keeps land off the tax roles when used by the public sector, which lowers income to the government. Problems arise in the private sector when there is no repurchase option and the value of the property appreciates. Without this option, the lessee will not share in any value increases.

D.17 SALES AGREEMENT

An essential ingredient in transferring real estate into a valuable commodity is the written agreement. A contract is a legally binding document in which certain parties agree to do or refrain from doing some action. The sales agreement is a legal contract which can be enforced through the legal process by either of the parties if the other party does not willingly comply with contract terms.

A sales agreement is needed to establish the terms agreed upon by the seller and buyer. Final acceptance of the purchase or sales agreement may be conditional upon proof of a clear title, rezoning to fit the land-use plans of the buyer, or adequate financing from lenders. The minimum requirements for a sales contract are the parties' agreement to conditions of the sale, a description of the property, and signatures of the agreeing parties. An installation, through sales agreements, can restrict the use of surrounding lands if they own or control them. Of course, the buyer must accept the terms of the sales agreement.

- **Positive Features of Sales Agreements.** After signing, the sales agreement is a legally binding contract. The buyer and/or seller can seek legal recourse through the courts if the contract is broken.

- **Negative Features of Sales Agreements.** Unlike the restrictive covenant, the sales agreement pertains only to the prospective buyer. The agreement does not carry over to future sales of the property unless so stated in the contract. In addition, certain areas of agreements and contracts are subject to possible misrepresentation and fraud.

D.18 DEED/COVENANTS

A deed is the document conveying ownership of land from one party to another. Restrictions (known as "covenants") can be added to become an integral part of the deed. Such covenants specify the uses that the new owner may make of the land. Deed restrictions apply in addition to any zoning laws. They may even supersede the zoning law by prohibiting a specified use that might otherwise be legal from a zoning standpoint. Restrictive covenants are known technically as "running with the land".

That is, no matter how often the land is subsequently resold, these restrictions remain in effect. They are a part of the land. There is usually a time limit placed on covenants of 20 to 30 years, after which they are no longer in effect. In certain instances, restrictions that have become impractical can be legally removed by the landowner, if deemed justifiable by the courts.

For deed restrictions to be an effective tool, the installation must first own or acquire the property surrounding the installation. In later reselling this property, agents can specify which uses will be permitted on the land. The government can thereby prevent residential (or otherwise incompatible) land uses for as long as the restrictions remain in effect. This method is particularly useful in controlling development on the property most vulnerable to installation noise.

- **Positive Features of Deed/Covenants.** This method is attractive because the installation retains control over surrounding land uses without needing to continue ownership of the land, thus lessening the tax burden. Deed restrictions are legally enforceable; regardless of how many times the property is resold.

- **Negative Features of Deed Covenants.** Some minor problems are associated with this method. The amount of land originally purchased for an Army installation must exceed the amount actually needed. This situation may present an excessive financial burden. Also, placing land-use restrictions in the deed might hinder attempts to sell the land later.

D.19 PURCHASE OF DEVELOPMENT RIGHTS

A title to real property contains several rights, including that of development. By purchasing this one right, incompatible land uses near Army installations might be prevented. Purchase of development rights would resemble a fee-simple purchase in terms of actual transaction and necessary legal paperwork. The difference would be that only one right is purchased rather than all of them. The development right of any property is usually the most valuable and desirable. The cost of the right is equal to the difference between the value of that parcel at its highest and best use and its existing value. A program of purchasing development rights could be used when insufficient funds are available for fee-simple purchases of land. The program would work best where development rights of agricultural land are purchased; the land would remain productive and yet no incompatible use could be developed.

- **Positive Features of Purchasing Development Rights.** By purchasing development rights, land uses adjoining Army installations can be kept compatible. The purchase of these rights on lands surrounding an Army installation would thus achieve the goal of preventing development of any kind. After all the purchases have been made, no more administrative work would be needed. If the program could be completed in a relatively short period of time, administrative and land acquisition costs could be reduced. Also, purchasing development rights is much less expensive, in most cases, than fee-simple purchase.

- **Negative Features of Purchasing Development Rights.** Such a program requires major expenditure of funds because of the amount of land that encompasses Army installations. Unwilling sellers may present a problem as well. If the highest and best use of the land is a high density one (e.g., multifamily), the price of the development rights would not be much less than that of fee-simple ownership.

D.20 EMINENT DOMAIN

Eminent domain is a police power that enables governments to condemn and subsequently acquire private property for a public use. The public purchase clause is important in eminent domain proceedings. This clause allows local governments to use eminent domain for a wide variety of acquisitions. Exercising eminent domain forces an owner to sell his/her property for just compensation, regardless of the owner's desires. The sale price is determined by independent appraisals (usually three). If an agreement cannot be reached, the courts will determine the compensation price. Eminent domain can be used to create open space in a municipality. It is usually implemented as a last resort when property cannot be acquired or controlled by other methods. Property around an installation would be condemned and subsequently purchased. By paying for the property, the Army would receive clear title to it and thus control all rights.

- **Positive Features of Eminent Domain.** Like other acquisition methods, eminent domain allows the government to own full rights to the property. Eminent domain powers can be delegated or legislated to units other than city or county governments, such as park districts.

- **Negative Features of Eminent Domain.** Eminent domain requires an expenditure of money to control the property. Also, eminent domain proceedings often result in litigation. If so, acquisition of the property may take years, if it occurs at all. Furthermore, eminent domain can be used to obtain only that land which is necessary.

D.21 PURCHASE OPTION

An option is an agreement between the buyer and seller of a piece of property. In the agreement, the seller will hold the property for a specified time. In turn, the buyer agrees to pay a sum of money as consideration for the offer. At the time the option is granted, no real property ownership rights pass. Instead, the buyer is purchasing the right to buy at a fixed price within a specified period of time. The seller retains the money paid regardless of whether the option is exercised. Option costs vary, but usually include the property taxes and a standard interest charge. The option can be used when funds cannot be acquired to purchase the property outright. During the period of the option, funds presumably can be obtained to make the purchase. This period can also be used to examine rezoning possibilities or other actions that would affect ownership of the property.

- **Positive Features of Purchase Option.** As mentioned above, an option allows the buyer time to locate and secure funds necessary to make the final purchase. Also, the option prevents others from developing the property in a way unacceptable to the installation.

- **Negative Features of Purchase Option.** This technique requires expenditure of funds to purchase the option. Even more funds must be appropriated if the option is set up to be renewed continuously.

D.22 TECHNIQUES FOR DEALING WITH NOISE IN LAND USE PLANNING (FICUN 1980)

TECHNIQUE	SITUATION WHERE MOST APPLICABLE	COMMENTS
Increased Citizen Awareness:		
Citizen Education	Anywhere	Can be an important factor in determining the marketability of homes and other land uses. Can have a direct effect on developers and builders. Use in combination with other actions.
Prior Notice of Noise Levels to Renters and Purchasers	Anywhere	Can be required by local ordinance. Enable renters and purchasers to choose environment will full information. May reduce or eliminate subsequent complaints or damage claims.
Coordination:		
OMB Cir A-95 Process	Where Federal and Federally-assisted Projects are Proposed.	Allows identification of noise problems in the review and comment of Federal and Federally assisted plans, programs and projects. Indirect control.
Environmental Assessment Process	Anywhere Environmental Impact Analyses are required.	Indirect control. Increase awareness of noise. May discourage Inappropriate projects. A mechanism to propose mitigation measures.

TECHNIQUE	SITUATION WHERE MOST APPLICABLE	COMMENTS
Providing Advisory Services:		
Architectural and/or Planning Review	Where there is appropriate staff or funding.	Site-specific analysis for each case.
Design Assistance	Where there is appropriate staff or funding.	Allows inclusion of noise mitigation measures such as building attenuation, site modification, berms, and barriers, etc.
Information Libraries	Anywhere	Passive advisory service.
Comprehensive Planning Process:		
Incorporating noise issues into Comprehensive Planning Process	Where comprehensive planning process is established particularly when controls (zoning) must implement plan.	Works best when noise is considered a basic suitability factor along with others such as slope, soil conditions, etc. Should be addressed in all types of plans. May require enabling legislation.
Environmental Management Programs:		
Incorporating noise issues into Environmental Management Programs	Where programs such as Area-wide Waste Management, Air Quality, Coastal Zone Management, Prime and Unique Agricultural Lands, Floodplain and Wetlands are established.	These programs influence land use policy.

TECHNIQUE	SITUATION WHERE MOST APPLICABLE	COMMENTS
Development Codes and Policies:		
Subdivision Regulations and/ or site plan approvals.	Where portions of development projects fall within noise exposure areas	May not be applicable for airborne aircraft. May require enabling legislation. Require noise considerations in site design (orientation, buffers, barriers, etc.).
Building Codes. Require sound insulation, isolation, absorption in building construction.	Where interior noise exposure can be reduced to acceptable levels and buildings should otherwise be prohibited.	Noise Level Reduction (NLR) up to 35 dB (15 dB above normal construction). Outdoor environment not protected. May require enabling legislation to use noise zones for building code restrictions. Difficult to apply retro-actively. Local opposition to increased building costs possibly related to energy conservation. Requirements might also be incorporated into health and/or occupancy codes.
Special Permits and/or Special Planning Districts	Anywhere a permit granting system exists or can be started.	Site-specific analysis would be required for each case. May require enabling legislation.

TECHNIQUE	SITUATION WHERE MOST APPLICABLE	COMMENTS
Special Use Designations	Anywhere unique or special land characteristics exist (cultural or historic, scenic, wetlands, floodplain, prime agricultural lands, water supply).	Such areas may be noise exposed and those designations will normally assure noise compatibility. May require legislation.
Official Map	Anywhere streets exist or are planned.	Planned major streets should avoid noise sensitive areas and should encourage development in areas not exposed to noise.
Capital Improvements	Anywhere.	Governmental constructed utilities, streets, and facilities should be sited to encourage compatible use and be in themselves compatible.
Land Use Controls (Zoning):		
For Compatible Land Uses	Anywhere.	Should be based on a comprehensive plan. May require enabling legislation to use noise as a criterion. Not retroactive and can be removed upon short notice. Most effective for undeveloped areas.
To Require Buffer Areas	Where noise source is at ground level.	Easy to implement in low density areas. Not effective for airborne aircraft. May require enabling legislation.

TECHNIQUE	SITUATION WHERE MOST APPLICABLE	COMMENTS
To Require Berms or Barriers	Where noise source is at ground level.	Effective, but care is needed to insure that it is aesthetically desirable. May require enabling legislation.
To Allow Cluster or Planned Unit Development	For medium and large developments.	Significant potential benefits. Builders can incorporate buffer areas without reducing number of units. May require enabling legislation.
Purchase Real Property Interests:		
Fee Purchase for Compatibility	Where noise levels are extreme.	Attempts to contain worst noise effects within the right-of-way or site. May require enabling legislation.
Fee Purchase for Public Use	Where public use is compatible and needed in that location.	Limited by need for compatible public uses.
Fee Purchase and Resale with Development Restrictions	Where other measures are are impractical.	Public authority may be reluctant. Local government may object to controls. Business may object to government becoming developer. Dependent on demand feasibility for compatible use. May require enabling legislation.
Easement (Development Rights) Purchase	Where other measures are impractical.	May be more practical than Fee Simple purchase. May require enabling legislation.

TECHNIQUE	SITUATION WHERE MOST APPLICABLE	COMMENTS
Agricultural Land Preservation District	Where land is suitable.	Requires appropriate legislation. Minimum site size of 50 acres is typical and usually allows a single farm residence. Presents possible bird strike hazards.
Property Tax Incentives:		
Property Tax Incentive (Open Space, Agricultural, etc.)	Where tax pressures exist on owners of undeveloped	Requires enabling legislation. Easy in many cases to implement. Cannot prevent incompatible development but can allow economically productive compatible land use.

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APPENDIX E

GUIDELINES FOR COMPATIBLE LAND USE

E.1 DOD COMPATIBLE LAND USE GUIDELINES FOR CLEAR ZONES AND ACCIDENT POTENTIAL ZONES (U.S. Army 1981)

LAND USE CATEGORY	COMPATIBILITY[1]		
	CLEAR ZONE	APZ I	APZ II
A. RESIDENTIAL			
Single Family Unit	No	No	Yes[2]
2-4 Family Units	No	No	No
Multifamily Dwellings (Apartments)	No	No	No
Group Quarters	No	No	No
Residential Hotels	No	No	No
Mobile Home Parks or Courts	No	No	No
Other Residential	No	No	No
B. INDUSTRIAL & MANUFACTURING[3]			
Food and Kindred Products	No	No	Yes
Textile Mill Products	No	No	Yes
Apparel	No	No	No
Lumber and Wood Products	No	Yes	Yes
Furniture and Fixtures	No	Yes	Yes
Paper and Allied Products	No	Yes	Yes
Printing, Publishing	No	Yes	Yes
Chemicals and Allied Products	No	No	No
Petroleum Refining and Related Industries	No	No	No
Rubber and Miscellaneous Plastic Goods	No	No	No
Stone, Clay and Glass Products	No	Yes	Yes
Primary Metal Industries	No	Yes	Yes
Fabricated Metal Products	No	Yes	Yes
Professional, Scientific and Controlling Instruments	No	No	No
Miscellaneous Manufacturing	No	Yes	Yes

LAND USE CATEGORY	COMPATIBILITY[1] CLEAR ZONE	APZ I	APZ II
C. TRANSPORTATION, COMMUNICATIONS & UTILITIES[4]			
Railroad, Rapid Rail Transit (on-grade)	No	Yes[4]	Yes
Highway and Street Rights-of-Way	Yes[5]	Yes	Yes
Auto Parking	No	Yes	Yes
Communications	Yes[5]	Yes	Yes
Utilities	Yes[5]	Yes[4]	Yes
Other Transportation, Communications and Utilities	Yes[5]	Yes	Yes
D. COMMERCIAL & RETAIL TRADE			
Wholesale Trade	No	Yes	Yes
Building Materials (Retail)	No	Yes	Yes
General Merchandise (Retail)	No	No	Yes
Food (Retail)	No	No	Yes
Automotive, Marine, and Aviation (Retail)	No	Yes	Yes
Apparel and Accessories (Retail)	No	No	Yes
Furniture, Home Furnishings (Retail)	No	No	Yes
Eating and Drinking Facilities	No	No	No
Other Retail Trade	No	No	Yes
E. PERSONAL & BUSINESS SERVICES[6]			
Finance, Insurance, and Real Estate	No	No	Yes
Personal Services	No	No	Yes
Business Services	No	No	Yes
Repair Services	No	Yes	Yes
Professional Services	No	No	Yes
Contract Construction Services	No	Yes	Yes
Indoor Recreation Services	No	No	Yes
Other Services	No	No	Yes
F. PUBLIC AND QUASI-PUBLIC SERVICES			
Government Services	No	No	Yes[6]
Educational Services	No	No	No
Cultural Activities	No	No	No
Medical and Other Health Services	No	No	No
Cemeteries	No	Yes[7]	Yes[7]
Non-profit Organizations Including Churches	No	No	No

LAND USE CATEGORY	COMPATIBILITY[1]		
	CLEAR ZONE	APZ I	APZ II
Other Public and Quasi-Public Services	No	No	Yes
G. OUTDOOR RECREATION			
Playgrounds and Neighborhood Parks	No	No	Yes
Community and Regional Parks	No	Yes[8]	Yes[8]
Nature Exhibits	No	Yes	Yes
Spectator Sports Including Arenas	No	No	No
Golf Courses[9], Riding Stables[10]	No	Yes	Yes
Water Based Recreational Areas	No	Yes	Yes
Resort and Group Camps	No	No	No
Entertainment Assembly Areas	No	No	No
Other Outdoor Recreation	No	Yes[8]	Yes
H. RESOURCE PRODUCTION & EXTRACTION & OPEN LAND			
Agriculture[11]	Yes	Yes	Yes
Livestock Farming, Animal Breeding[12]	No	Yes	Yes
Forestry Activities	No	Yes	Yes
Fishing Activities and Related Services[13]	No[14]	Yes[13]	Yes
Mining Activities	No	Yes	Yes
Permanent Open Space	Yes	Yes	Yes
Water Areas[13]	Yes	Yes	Yes

Footnotes:

1 A "Yes" or "No" designation for compatible land use is to be used only for gross comparison. Within each, uses exist where further definition may be needed as to whether it is clear or usually acceptable/unacceptable owing to variations in densities of people and structures. For heliports and stagefields, the takeoff safety zone is equivalent to the clear zone and the approach-departure zone is equivalent to APZ I for these land use guidelines.

2 Suggested maximum density 1-2 dwelling units per acre; possibly increased under a Planned Unit Development where maximum lot coverage is less than 20 percent.

3 Factors to be considered: Labor intensity, structural coverage, explosive characteristics, and air pollution.

4 No passenger terminals and no major above ground transmission lines in APZ I.

[5] Not permitted in graded area, except as noted in Table 2-7, TM 5-803-7.

[6] Low intensity office uses only. Meeting places, auditoriums, etc., not recommended.

[7] Excludes chapels.

[8] Facilities must be low intensity.

[9] Clubhouse not recommended.

[10] Concentrated rings with large classes not recommended.

[11] Includes livestock grazing but excludes feedlots and intensive animal husbandry.

[12] Includes feedlots and intensive animal husbandry.

[13] Includes hunting and fishing.

[14] Controlled hunting and fishing may be permitted for the purpose of wildlife control.

E.2 GUIDELINES FOR CONSIDERING NOISE IN LAND USE PLANNING AND CONTROL (FICUN 1980)

		NOISE ZONES/ADNL LEVELS (dBA)						
		NZ I		NZ II		NZ III		
SLUCM No.	LAND USE	0-55	55-65	65-70	70-75	75-80	80-85	85+
10	**RESIDENTIAL**							
11	Household Units	Yes	Yes[*]	25[1]	30[1]	No	No	No
12	Group Quarters	Yes	Yes[*]	25[1]	30[1]	No	No	No
13	Residential Hotels	Yes	Yes[*]	25[1]	30[1]	No	No	No
14	Mobile Home Parks or Courts	Yes	Yes[*]	No	No	No	No	No
15	Transient Lodgings	Yes	Yes[*]	25[1]	30[1]	35[1]	No	No
16	Other Residential	Yes	Yes[*]	25[1]	30[1]	No	No	No
20,30	**MANUFACTURING**							
21	Food & Kindred Products Yes	Yes	Yes	Yes[2]	Yes[3]	Yes[4]	No	
22	Textile Mill Products	Yes	Yes	Yes	Yes[2]	Yes[3]	Yes[4]	No
23	Apparel/Other Finished Products	Yes	Yes	Yes	Yes[2]	Yes[3]	Yes[4]	No
24	Lumber & Wood Products	Yes	Yes	Yes	Yes[2]	Yes[3]	Yes[4]	No
25	Furniture & Fixtures	Yes	Yes	Yes	Yes[2]	Yes[3]	Yes[4]	No
26	Paper & Allied Products	Yes	Yes	Yes	Yes[2]	Yes[3]	Yes[4]	No
27	Printing, Publishing & Allied Industries	Yes	Yes	Yes	Yes[2]	Yes[3]	Yes[4]	No
28	Chemicals & Allied Products	Yes	Yes	Yes	Yes[2]	Yes[3]	Yes[4]	No
29	Petroleum Refining & Related Industries	Yes	Yes	Yes	Yes[2]	Yes[3]	Yes[4]	No
31	Rubber & Misc Plastic Products - Manufac	Yes	Yes	Yes	Yes[2]	Yes[3]	Yes[4]	No
32	Stone, Clay & Glass Products - Manufac	Yes	Yes	Yes	Yes[2]	Yes[3]	Yes[4]	No
33	Primary Metal Industries	Yes	Yes	Yes	Yes[2]	Yes[3]	Yes[4]	No

SLUCM No.	LAND USE	NZ I 0-55	NZ I 55-65	NZ II 65-70	NZ II 70-75	NZ III 75-80	NZ III 80-85	85+
	NOISE ZONES/ADNL LEVELS (dBA)							
20,30	**MANUFACTURING continued:**							
34	Fabricated Metal Products - Manufac	Yes	Yes	Yes	Yes[2]	Yes[3]	Yes[4]	No
35	Professional, Scientific & Controls	Yes	Yes	Yes	25	30	No	No
39	Miscellaneous Manufacturing	Yes	Yes	Yes	Yes[2]	Yes[3]	Yes[4]	No
40	**TRANSPORT, COMMS & UTIL**							
41	Railroad, Rapid Rail Transit & Street Rail	Yes	Yes	Yes	Yes[2]	Yes[3]	Yes[4]	Yes[4]
42	Motor Vehicle Transportation	Yes	Yes	Yes	Yes[2]	Yes[3]	Yes[4]	Yes[4]
43	Aircraft Transportation	Yes	Yes	Yes	Yes[2]	Yes[3]	Yes[4]	Yes[4]
44	Marine Craft Transportation	Yes	Yes	Yes	Yes[2]	Yes[3]	Yes[4]	Yes[4]
45	Highway & Street Right-of-Way	Yes	Yes	Yes	Yes[2]	Yes[3]	Yes[4]	Yes[4]
46	Automobile Parking	Yes	Yes	Yes	Yes[2]	Yes[3]	Yes[4]	No
47	Communications	Yes	Yes	Yes	25[5]	30[5]	No	No
48	Utilities	Yes	Yes	Yes	Yes[2]	Yes[3]	Yes[4]	Yes[4]
49	Other Transportation, Comms & Utilities	Yes	Yes	Yes	25[5]	30[5]	No	No
50	**TRADE**							
51	Wholesale Trade	Yes	Yes	Yes	Yes[2]	Yes[3]	Yes[4]	No
52	Retail - Building Materials, Hardware/ Farm	Yes	Yes	Yes	Yes[2]	Yes[3]	Yes[4]	No
53	Retail - General Merchandise	Yes	Yes	Yes	25	30	No	No
54	Retail - Food	Yes	Yes	Yes	25	30	No	No

SLUCM No.	LAND USE	NOISE ZONES/ADNL LEVELS (dBA) NZ I 0-55	55-65	NZ II 65-70	70-75	NZ III 75-80	80-85	85+
50	**TRADE continued:**							
55	Retail - Auto, Marine, Aircraft & Parts	Yes	Yes	Yes	25	30	No	No
56	Retail - Apparel & Accessories	Yes	Yes	Yes	25	30	No	No
57	Retail - Furniture, Furnishings & Equipment	Yes	Yes	Yes	25	30	No	No
58	Retail - Eating & Drinking Facilities	Yes	Yes	Yes	25	30	No	No
59	Other Retail Trade	Yes	Yes	Yes	25	30	No	No
60	**SERVICES**							
61	Finance, Insurance & Real Estate Services	Yes	Yes	Yes	25	30	No	No
62	Personal Services	Yes	Yes	Yes	25	30	No	No
62.4	Cemeteries[11]	Yes	Yes	Yes	Yes[2]	Yes[3]	Yes[4]	Yes[6]
63	Business Services	Yes	Yes	Yes	25	30	No	No
64	Repair Services	Yes	Yes	Yes	Yes[2]	Yes[3]	Yes[4]	No
65	Professional Services	Yes	Yes	Yes	25	30	No	No
65.1	Hospitals, Nursing Homes	Yes	Yes*	25*	30*	No	No	No
65.1	Other Medical Facilities	Yes	Yes	Yes	25	30	No	No
66	Contract Construction Services	Yes	Yes	Yes	25	30	No	No
67	Government Services	Yes	Yes*	Yes*	25*	30*	No	No
68	Educational Services	Yes	Yes*	25*	30*	No	No	No
69	Miscellaneous Services	Yes	Yes	Yes	25	30	No	No
70	**CULTURAL, ENTERTAINMENT & REC**							
71	Cultural Activities, Including Churches	Yes	Yes*	25*	30*	No	No	No
71.2	Nature Exhibits	Yes	Yes*	Yes*	No	No	No	No
72	Public Assembly	Yes	Yes	Yes	No	No	No	No

		NOISE ZONES/ADNL LEVELS (dBA)						
		NZ I		NZ II		NZ III		
SLUCM No.	LAND USE	0-55	55-65	65-70	70-75	75-80	80-85	85+
70	**CULTURAL, ENTERTAINMENT & REC continued:**							
72.1	Auditoriums, Concert Halls	Yes	Yes	25	30	No	No	No
72.11	Outdoor Music Shells, Amphitheaters	Yes	Yes*	No	No	No	No	No
72.2	Outdoor Sports Arenas, Spectator Sports	Yes	Yes	Yes[7]	Yes[7]	No	No	No
73	Amusements	Yes	Yes	Yes	Yes	No	No	No
74	Recreational Activities	Yes	Yes*	Yes*	25*	30*	No	No
75	Resorts, Groups & Camps	Yes	Yes*	Yes*	Yes*	No	No	No
76	Parks	Yes	Yes*	Yes*	Yes*	No	No	No
79	Other Cultural, Entertainment & Recreation	Yes	Yes*	Yes*	Yes*	No	No	No
80	**RESOURCE PRODUCT & EXTRACT**							
81	Agriculture (Except Livestock)[11]	Yes	Yes	Yes[8]	Yes[9]	Yes[10]	Yes[10]	Yes[10]
81.5-81.7	Livestock Farming & Animal Breeding	Yes	Yes	Yes[8]	Yes[9]	No	No	No
82	Agricultural Related Activities[11]	Yes	Yes	Yes[8]	Yes[9]	Yes[10]	Yes[10]	Yes[10]
83	Forestry Activities & Related Services[11]	Yes	Yes	Yes[8]	Yes[9]	Yes[10]	Yes[10]	Yes[10]
84	Fishing Activities & Related Services	Yes	Yes	Yes	Yes	Yes	Yes	Yes
85	Mining Activities & Related Services	Yes	Yes	Yes	Yes	Yes	Yes	Yes
89	Other Resource Production & Extraction	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Legend:

SLCUM	Standard Land Use Coding Manual
Yes	Land use and related structures compatible without restrictions.
No	Land use and related structures are not compatible and should be prohibited.
ADNL	A-weighted day-night sound level
NZ	Noise Zone
Yes[x]	"Yes", but with restrictions. Land use and related structures generally compatible; see footnotes.
25, 30, 35	Land use and related structures generally compatible; measures to achieve noise level reduction (NLR) of 25, 30 or 35 must be incorporated into design and construction of structure.
25*, 30*, 35*	Land use generally compatible with NLR; however, measures to achieve an overall NLR do not necessarily solve noise difficulties and additional evaluation is warranted.
NLR	Noise Level Reduction (outdoor to indoor) to be achieved through incorporation of noise attenuation into the design and construction of the structure.

Footnotes:

* The designation of these uses as "compatible" in this zone reflects individual Federal agencies' consideration of general cost and feasibility factors as well as past community experiences and program objectives. Localities, when evaluating the application of these guidelines to specific situations, may have different concerns or goals to consider.

a) Although local conditions may require residential use, it is discouraged in 65-70 ADNL and strongly discouraged in 70-75 ADNL. The absence of viable alternative development options should be determined and an evaluation indicating that a demonstrated community need for residential use would not be met if development were prohibited in these zones should be conducted prior to approvals.

b) Where the community determines that residential uses must be allowed, measures to achieve outdoor to indoor NLR of at least 25 dB (65-70 ADNL) and 30 dB (70-75 ADNL) should be incorporated into building codes and be considered in individual approvals. Normal construction can be expected to provide a NLR of 20 dB, thus the reduction requirements are often stated as 5, 10, or 15 dB over standard construction and normally assume mechanical ventilation and closed windows year round. Additional consideration should be given to modifying NLR levels based on peak noise levels.

c) NLR criteria will not eliminate outdoor noise problems. However, building location and site planning, design, and use of berms and barriers can help mitigate outdoor noise exposure particularly from ground level transportation sources. Measures that reduce noise at a site should be used wherever practical in preference to measures that only protect interior spaces.

[2] Measures to achieve NLR of 25 must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise-sensitive areas, or where the normal noise level is low.

[3] Measures to achieve NLR of 30 must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise-sensitive areas, or where the normal noise level is low.

[4] Measures to achieve NLR of 35 must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise-sensitive areas, or where the normal noise level is low.

[5] If noise-sensitive, use indicated NLR; if not, use is compatible.

[6] No buildings.

[7] Land use compatible provided special sound reinforcement systems are installed.

[8] Residential buildings require a NLR of 25.

[9] Residential buildings require a NLR of 30.

[10] Residential buildings not permitted.

[11] In areas with ADNL greater than 80, land use not recommended, but if community decides use is necessary, hearing protection devices should be worn by personnel.

APPENDIX F

GLOSSARY OF TERMS, ACRONYMS & ABBREVIATIONS

F.1 GLOSSARY OF TERMS

A-Weighted Sound Level, A-Level (AL) - The ear does not respond equally to sounds of all frequencies, but is less efficient at low and high frequencies than it is at medium or speech range frequencies. Thus, to obtain a single number representing the sound pressure level of a noise containing a wide range of frequencies in a manner approximating the response of the ear, it is necessary to reduce, or weight, the effects of the low and high frequencies with respect to the medium frequencies. Thus, the low and high frequencies are de-emphasized with the A-weighting.

The A-scale sound level is a quantity, in decibels, read from a standard sound-level meter with A-weighting circuitry. The A-scale weighting discriminates against the lower frequencies according to a relationship approximating the auditory sensitivity of the human ear. The A-scale sound level measures approximately the relative "noisiness" or "annoyance" of many common sounds.

Accident Potential Zones (APZ) – APZs are areas on the ground beyond the clear zone of each runway. They possess a potential for accidents and their use is restricted in accordance with DODI 4165.57. The dimensional requirements for APZ I and APZ II are specified by each Service in Air Force Manual 32-1123(I), Army Technical Manual TM 5-803-7 and Naval Facilities Engineering Command Publication P-971, Airfield and Heliport Planning and Design.

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Accident Potential Zone I - The APZ I is located just beyond the Clear Zones at each end of the runway. Less critical than the Clear Zone it still possesses significant potential for accidents. Land use compatibility guidelines allow a wide variety of industrial, manufacturing, transportation, communication, utilities, wholesale trade, open space, recreation and agricultural uses. Uses that concentrate people in small areas are not acceptable in APZ I. As an example the APZ I for an Army Class A Runway is an area 1,000 feet wide by 2,500 feet long

Accident Potential Zone II - The APZ II extends beyond APZ I. This area is less critical than APZ I but still possesses potential for accidents. Acceptable land uses include those in APZ I, as well as low density, single family residences. Also acceptable are personal and business services and commercial retail trade uses of low intensity or scale of operation. High-density functions such as multi-story buildings, places of assembly (e.g., theaters, schools, churches, and restaurants) and high-density office uses are not considered appropriate. As an example the APZ II for an Army Class A Runway is an area 1,000 feet wide by 2,500 feet long.

Aircraft - fixed-wing (FW) (Airplane) and rotary-wing (RW) (Helicopter).

Airfield - an area prepared for the accommodation (including any buildings, installations, and equipment), landing and takeoff of aircraft.

Annual Average Busy Day - average of the 12 monthly averages of workday operations. This is obtained by computing a workday average over a monthly period for each month and then averaging the 12 values.

Approach-Departure Zone - an area on ground or water located beneath the approach-departure clearance surface. It begins at the outer edge of the Takeoff Safety Zone and the boundaries are identical to the horizontal dimensions of the approach-departure clearance surface. It corresponds to the Accident Potential Zone I for land use planning purposes.

Approach-Departure Clearance Surface (VFR) - an inclined plane above the limits of the approach-departure zone, symmetrical about the runway or helipad extended longitudinal centerline. It starts at the end of the primary surface with the same width and at the established elevation of the landing surface. It extends outward and upward at a slope ratio of 8 to 1 until an elevation of 150 feet above the established helicopter runway or helipad elevation is reached. The outer width at the end of the 1,200 foot length is 600 feet, and it continues at this width until the minimum en route altitude is reached. Note: When helicopter facilities are located separately, from fixed-wing runways, the approach-departure clearance surface extends horizontally to the limits of that surface and then continues on an 8 to 1 slope ratio until minimum en route altitude is reached.

Average Sound Level - the mean-squared sound exposure level of all events occurring in a stated time interval, plus ten times the common logarithm of the quotient formed by the number of events in the time interval, divided by the duration of the time interval in seconds.

C-Weighted Sound Level, C-Level (CL) - a quantity, in decibels, read from a standard sound level meter with C-weighting circuitry. The C-scale incorporates slight de-emphasis of the low and high portion of the audible frequency spectrum.

Class A Runway - a runway intended primarily for small light aircraft. Such runways either do not have the potential for development for use by heavy aircraft or there is no foreseeable requirement for such use. Ordinarily, less than 10 percent of the operations at airfields with Class A runways involve aircraft in the Class B category and the runway(s) are less than 8,000 feet long.

Class B Runway - all runways other than Class A runways, for example, runways that accommodate heavy aircraft or have the potential for development to heavy aircraft use.

Clear Zone (CZ) – The CZ is located at the immediate end of the runway. The accident potential in this area is so high that no building is allowed. For safety reasons, the DOD is authorized to purchase the land for these areas if not already part of the installation. As an example the CZ for an Army Class A Runway is an area 1,000 feet wide by 3,000 feet long

Community - those individuals, organizations, or special interest groups affected by or interested in decisions affecting towns, cities, or unincorporated areas near or adjoining a military installation; and officials of local, state and federal governments, and Native American tribal councils responsible for decision making and administration of programs affecting those communities.

Community Involvement Program - a carefully designed program using a variety of techniques (which, in addition to, informing the public of possible decisions and their potential consequences) provides opportunities for consultation with the public, and considers the public’s views before making decisions and taking actions.

Continuous Noise - on-going noise, whose intensity, remains at a measurable level without interruption over an indefinite or a specified period of time.

Controlled Firing Area - airspace wherein firing activities are conducted under conditions so controlled as to eliminate hazardous to nonparticipating aircraft and to ensure the safety of persons and property on the ground.

Day-Night Average Sound Level (DNL) - the 24-hour average frequency-weighted sound level, in decibels, from midnight to midnight, obtained after addition of 10 decibels to sound levels in the night from midnight up to 7 a.m. and from 10 p.m. to midnight (0000 up to 0700 and 2200 up to 2400 hours). A-Weighting is understood unless otherwise specified.
Decibels (dB) - a logarithmic sound pressure unit of measure.

Encroachment - unguided use or development of the land surrounding a military installation.

Equivalent Sound Level (LEQ) - the level of a constant sound which, in a given situation and time period, has the same energy as does a time varying sound. For noise sources, which are not in continuous operation, the equivalent sound level may be obtained by summing individual sound exposure level (SEL) values and normalizing over the appropriate time period.

Established Airfield Elevation - the elevation, (in feet above mean sea level), of the highest point on the usable landing surface.

Fixed-Wing Aircraft - a powered aircraft that has wings attached to the fuselage so that they are either rigidly fixed in place or adjustable, as distinguished from aircraft with rotating wings, like a helicopter.

Frequency - number of complete oscillation cycles per unit of time. The unit of frequency is the Hertz (Hz).

Helicopter - an aircraft deriving both lift and control from one or more power driven rotors, rotating on substantially vertical axes.

Hertz - unit of frequency equal to one cycle per second.

Impulse Noise (Impulsive Noise) - noise of short duration (typically less than one second), especially of high intensity, abrupt onset and rapid decay, and often rapidly changing spectral composition. Impulse noise is characteristically associated with such sources as explosions, impacts, the discharge of firearms, the passage of supersonic aircraft (sonic boom) and many industrial processes.

Instrument Flight Rules (IFR) - rules that govern the procedure for conducting instrument flight.

Intermittent Noise - fluctuating noise, whose level falls one or more times to low or immeasurable values during an exposure.

Military Operations Area (MOA) - a special use airspace assignment of defined vertical and lateral dimensions established outside positive control areas to separate/segregate certain military activities from IFR traffic and to identify for VFR traffic where these activities are conducted.

Modularity – the military concept where forces are constructed of highly skilled relatively standardized units (training and equipment) to maintain the greatest possible combat flexibility.

Noise - any sound without value.

Noise Exposure - the cumulative acoustic stimulation reaching the ear of a person, over a specified period of time, (e.g., a work shift, a day, or a lifetime).

Noise Hazard (Hazardous Noise) - acoustic stimulation of the ear that is likely to produce noise-induced permanent threshold shift in some portion of the population.

Noise Level Reduction (NLR) - the difference, measured in decibels, between the A-weighted sound level outside a building and the A-weighted sound level inside a designated room in the building. The NLR is dependent upon the transmission loss characteristics of the building surfaces exposed to an exterior noise source, the particular noise characteristics of the exterior noise source and the acoustic properties of the designated room in the building.

Noise Zone III - consists of an area around the source of the noise in which the day-night sound level (DNL) is greater than 75 decibels, A-weighted (dBA) or 70 decibels, C-weighted (dBC). Within NZ III noise-sensitive activities are not recommended.

Noise Zone II - consists of an area where the day-night sound level is between 65 and 75 dBA or 62 and 70 dBC. The land within NZ II should normally be limited to activities such as industrial, manufacturing, transportation and resource production and noise-sensitive land uses are normally not recommended.

Noise Zone I - includes all areas around a noise source in which the day-night sound level is less than 65 dBA or 62 dBC. This area is usually acceptable for all types of land use activities.

Obstacle - a natural or manmade object that violates airfield or heliport clearances, or projects into imaginary airspace surfaces.

PK 15(met) - the metric Pk 15(met) accounts for statistical variation in received single event peak noise level that is due to weather. It is the calculated peak noise level, without frequency weighting, expected to be exceeded by 15 percent of all events that might occur. If there are multiple weapon types fired from one location, or multiple firing locations, the single event level used should be the loudest level that occurs at each receiver location.

Prohibited Area - designated airspace within which the flight of aircraft is prohibited (Refer to Enroute Charts).

Public - the same thing as "community" (for the purposes of this management plan).

Public Information Program - a carefully designed effort using a variety of techniques to inform those people, most likely, to be interested or affected by actions resulting from the Environmental Noise Management Program and Plan.

Restricted Area - airspace designated under FAR, Part 73, within which the flight of aircraft, while not wholly prohibited, is subject to restriction. Most restricted areas are designated joint use and IFR/VFR operations in the area may be authorized by controlling ATC facility when it is not being utilized by the using agency. Restricted areas are depicted on Enroute charts. Where joint use is authorized, the name of the ATC controlling facility is also shown. (Refer to FAR, Part 73)

Runway - a designated rectangular area, on an airfield or heliport prepared for the landing and takeoff run of aircraft along its length.

Scaled Distance - parameter used by the mining industry and equal to the source-to-receiver distance divided by the cube root of the mass of the explosive material, $S=d/m^{1/3}$, with distance d in feet and explosive mass m in pounds. Unit = feet per cube root of pounds.

Sound Exposure Level (SEL) - the level of the sound pressure squared, integrated over a given time.

Sound Level Meter - an instrument that provides a direct reading of the sound pressure level at a particular location. It consists of a microphone and electronic amplifier together with a meter having a scale graduated in decibels. Using appropriate built-in electrical filters, it is possible to directly measure the overall A- and C-weighted sound pressure levels. Standard sound level meters must satisfy the requirements of American National Standards Institute (ANSI) Specification for Sound Level Meters, S1.4-1983.

Standard Land Use Coding Manual (SLUCM) - standard system for identifying and coding land use activities. Published by the U.S. Department of Commerce; 1965.

Vibration - an oscillation where the quantity is a parameter that defines the motion of a mechanical system.

Visual Flight Rules (VFR) - rules that govern the procedures for conducting flight under visual conditions.

Warning Area - special use airspace, (which may contain hazards to nonparticipating aircraft), in international airspace.

F.2 GLOSSARY OF ACRONYMS AND ABBREVIATIONS.

A

AAF	Army Airfield
ADNL	A-weighted Day-Night Average Sound Level
A-DZ	Approach-Departure Zone
AGL	Above Ground Level
AHO	Above Highest Obstacle
AL	A-weighted Sound Level
ANSI	American National Standards Institute
AO	Area of Operation
APZ	Accident Potential Zone
APZ I	Accident Potential Zone I
APZ II	Accident Potential Zone II
AR	Army Regulation
ARNG	Army National Guard
ATC	Air Traffic Control

B

BN	Battalion

C

CDNL	C-weighted Day-Night Level
CHABA	National Academy of Sciences Committee on Hearing, Bioacoustics and Biomechanics
CIP	Capital Improvement Program
CL	C-weighted Sound Level
CZ	Clear Zone

D

DA	Department of the Army
dB	Decibels
dBA	Decibels, A-weighted
dBC	Decibels, C-weighted
dBP	Decibels, Unweighted Peak
DNL	Day-Night Average Sound Level
DOD	Department of Defense
DODI	Department of Defense Instruction

E

EA	Environmental Assessment
EDA	Economically Distressed Area
EEO	Equal Employment Opportunity
EIS	Environmental Impact Statement
EJ	Environmental Justice
ENMP	Environmental Noise Management Plan
EOD	Explosive Ordnance Disposal
EPA	Environmental Protection Agency

F

FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FICUN	Federal Interagency Committee on Urban
Noise	
FORSCOM	U.S. Army Forces Command
FW	Fixed-wing Aircraft
FY	Fiscal Year

G

GIS	Geographic Information System

H

HQ	Headquarters
HQDA	Headquarters, Department of the Army
HR	U.S. House of Representatives
HUD	U.S. Department of Housing and Urban Development

H

Hz	Hertz

I

ICUZ	Installation Compatible Use Zone
IFR	Instrument Flight Rules
IG	Inspector General
IONMP	Installation Operational Noise Management Plan

J

JLUS	Joint Land Use Study

K

None

L

ADNL	A-weighted Day-Night Sound Level
CDNL	C-weighted Day-Night Sound Level
LEQ	Equivalent Sound Level

M

MAST	Military Assistance to Safety and Traffic
MEDEVAC	Medical Evacuation
MMB	Multi-Media Branch
MOA	Military Operations Area
MP	Military Police
MTR	Military Training Route
MSL	Mean Sea Level

N

NAS	Naval Air Station
NAVAIDS	Aids to Navigation
NE	Northeast
NEPA	National Environmental Policy Act
NFS	National Forest Service
NGB	National Guard Bureau
NGA	National Geospatial Intelligence Agency
NLR	Noise Level Reduction
NOE	Nap of the Earth
NW	Northwest
NZ	Noise Zone
NZ I	Noise Zone I
NZ II	Noise Zone II
NZ III	Noise Zone III

O

OMB	Office of Management and Budget
ONMP	Operational Noise Management Plan

P

PAO	Public Affairs Officer
PL	Public Law
PMO	Provost Marshal Office

Q

None

R

R&D	Research and Development
RC	Reserve Components
ROTC	Reserve Officers Training Corps
RW	Rotary-wing Aircraft (Helicopter)

S

SCS	Soil Conservation Service (U.S.)
SE	Southeast
SEL	Sound Exposure Level
SGS	Secretary of the General Staff
SJA	Staff Judge Advocate
SLUCM	Standard Land Use Coding Manual
SONMP	Statewide Operational Noise Management Plan
SR	State Route
STC	Sound Transmission Class
SUA	Special Use Airspace
SW	Southwest

T

TDR	Transfer of Development Rights
TM	Technical Manual
TRADOC	U.S. Army Training and Doctrine Command

U

USACERL	U.S. Army Construction Engineering Research Laboratories
USACHPPM	U.S. Army Center for Health Promotion and Preventive Medicine
USAF	U.S. Air Force
USAR	U.S. Army Reserve
USC	U.S. Code

	USDA	U.S. Department of Agriculture
	USFWS	U.S. Fish and Wildlife Service
	USGS	U.S. Geological Service
V		
	VA	U.S. Department of Veterans Affairs
	VFR	Visual Flight Rules
	VMC	Visual Meteorological Conditions
W		
	None	
X		
	None	
Y		
	None	
Z		
	None	

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