Appendix U
Noise Methods of Analysis

Introduction

Noise is generally described as unwanted sound. Unwanted sound can be based on objective effects (hearing loss, damage to facilities, etc.) or subjective judgments (community annoyance). Noise analysis requires a combination of physical measurement of sound, physical and physiological effects, plus psycho- and socioacoustic effects.

Section 1.0 of this appendix describes how sound is predicted and measured, Section 2.0 describes the effect of noise on people, facilities, and wildlife, and Section 3.0 provides a summary description of the specific methods used to predict noise from Evolved Expendable Launch Vehicle (EELV) program activities.

1.0 Noise Descriptors and Prediction

EELV program launch vehicles would generate two types of sound—engine noise (continuous sound) and sonic booms (transient, impulsive sounds). These types of sounds are quantified in separate ways.

1.1 Noise Descriptors

Measurement and perception of sound involves two basic physical characteristics: amplitude and frequency. Amplitude is a measure of the strength of the sound and is directly measured in terms of the pressure of a sound wave. Because sound pressure varies in time, various types of pressure averages are usually used. Frequency, commonly perceived as pitch, is the number of times per second the sound causes air molecules to oscillate. Frequency is measured in units of cycles per second, or hertz (Hz).

Amplitude

The loudest sounds the human ear can comfortably hear have acoustic energy one trillion times the acoustic energy of sounds the ear can barely detect. Because of this vast range, attempts to represent sound amplitude by pressure are generally unwieldy. Sound is therefore usually represented on a logarithmic scale with a unit called the decibel (dB). Sound on the decibel scale is referred to as a sound level. The threshold of human hearing is approximately 0 dB, and the threshold of discomfort or pain is around 120 dB.

The difference in dB between two sounds represents the ratio of those two sounds. Because human senses tend to be proportional (i.e., detect whether one sound is twice as loud as another) rather than absolute (i.e., detect whether one sound is a given number of pressure units bigger than another), the decibel scale correlates well with human response.

Frequency

The normal human ear can hear frequencies from about 20 Hz to about 15,000 or 20,000 Hz. It is most sensitive to sounds in the 1,000 to 4,000 Hz range. When measuring community response to noise, it is common to adjust the frequency content of the measured sound to correspond to the frequency sensitivity of the human ear. This adjustment is called A-weighting (American National Standards Institute, 1988). Sound levels that have been so adjusted are referred to as A-weighted sound levels. The amplitude of A-weighted sound levels is measured in dB. It is common for some noise analysts to denote the unit of A-weighted sounds by dBA or dB(A). As long as the use of A-weighting is understood, there is no difference between dB, dBA or dB(A). It is only important that the use of A-weighting be made clear. It is common to use the term A-weighted sound pressure level (AWSPL) to refer to A-weighted sounds.

For analysis of damage to structures by sound, it is common not to apply any frequency weighting. Such overall sound levels are measured in dB and are often referred to as overall sound pressure levels (OASPL or OSPL).

C-weighting (American National Standards Institute, 1988) is sometimes applied to sound. This is a frequency weighting that is flat over the range of human hearing (about 20 Hz to 20,000 Hz) and rolls off above and below that range. C-weighted sound levels are often used to analyze high-amplitude impulsive noise, where adverse impact is influenced by rattle of buildings.

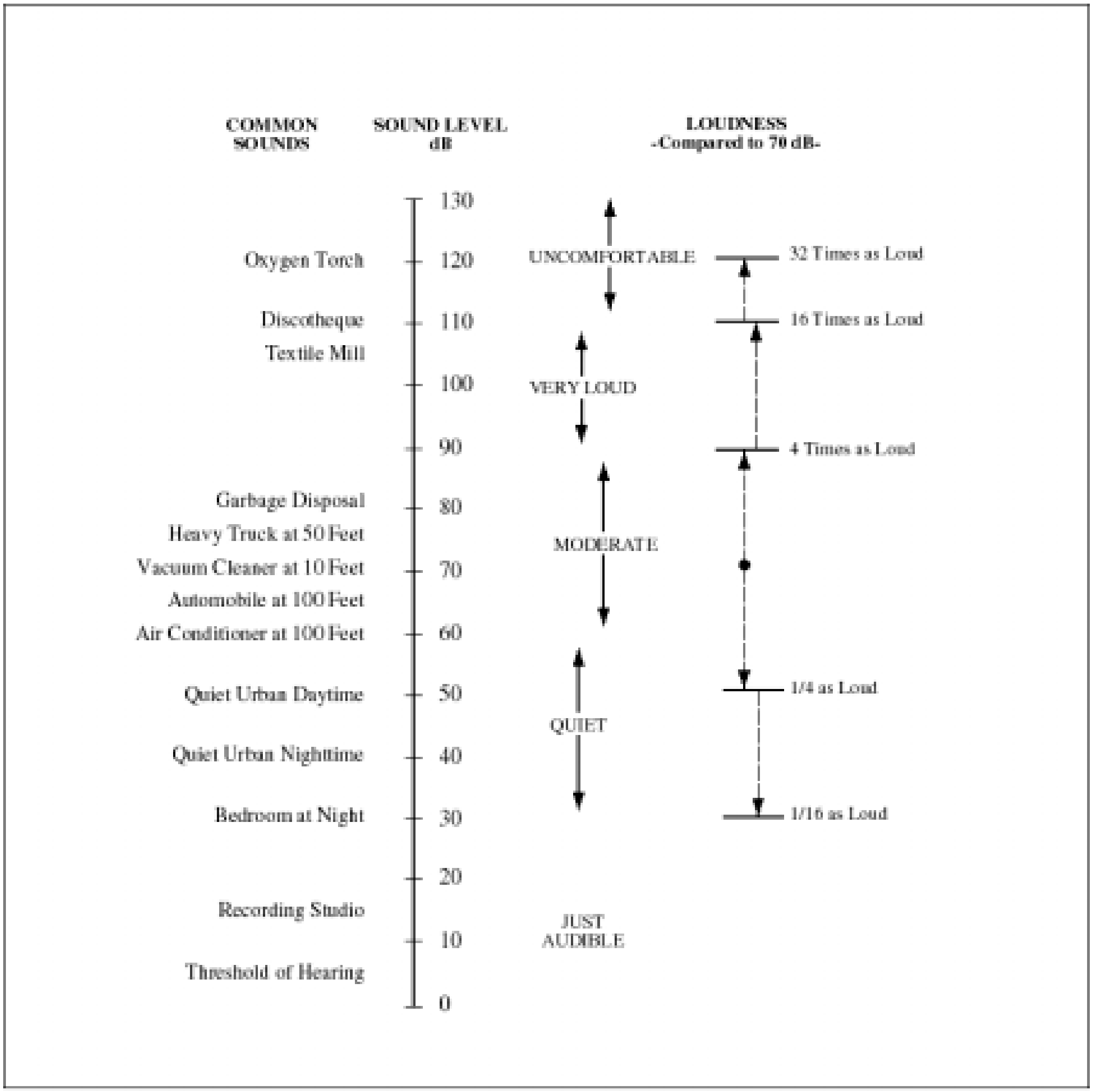
Time Averaging

Sound pressure of a continuous sound varies greatly with time, so it is customary to deal with sound levels that represent averages over time. Levels presented as instantaneous (i.e., as might be read from the dial of a sound level meter), are based on averages of sound energy over either 1/8 second (fast) or one second (slow). The formal definitions of fast and slow levels are somewhat complex, with details that are important to the makers and users of instrumentation. They may, however, be thought of as levels corresponding to the root-mean-square sound pressure measured over the 1/8-second or 1-second periods.

The most common uses of the fast or slow sound level in environmental analysis are in the discussion of the maximum sound level that occurs from the action, and in discussions of typical sound levels. Figure U-1 shows a chart of sound levels from typical sounds.

Assessment of cumulative noise impact requires average levels over periods longer than just the fast or slow times. The sound exposure level (SEL) sums the total sound energy over a noise event. Mathematically, the mean square sound pressure is computed over the duration of the event, then multiplied by the duration in seconds, and the resultant product is turned into a sound level. SEL is sometimes described as the level that, occurring for one second, would have the same sound energy as the actual event.

Note that SEL is a composite metric that combines both the amplitude of a sound and its duration. It is a better measure of noise impact than the maximum sound level alone, because it accounts for duration. Long sounds are more intrusive than short sounds of equal level, and it has been well established that SEL provides a good measure of this effect.



A-Weighted Sound Levels of Common Sounds

Figure U-1

Source: Handbook of Noise Control, C.M. Harris, Editor, McGraw-Hill Book Co., 1979

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SEL can be computed for A- or C-weighted levels, and the results can be denoted as ASEL or CSEL. It can also be computed for unweighted (overall) sound levels, with a corresponding designation.

For longer periods of time, total sound is represented by the equivalent continuous sound pressure level (L_{eq}). L_{eq} is the average sound level over some time period (often an hour or a day, but any explicit time span can be specified) with the averaging being done on the same energy basis as used for SEL. SEL and L_{eq} are closely related, differing according to: (a) whether they are applied over a specific time period or over an event, and (b) whether the duration of the event is included or divided out.

Just as SEL has proven to be a good measure of the noise impact of a single event, L_{eq} has been established to be a good measure of the impact of a series of events during a given time period. Also, while L_{eq} is defined as an average, it is effectively a sum over that time period, so is a measure of the cumulative impact of noise.

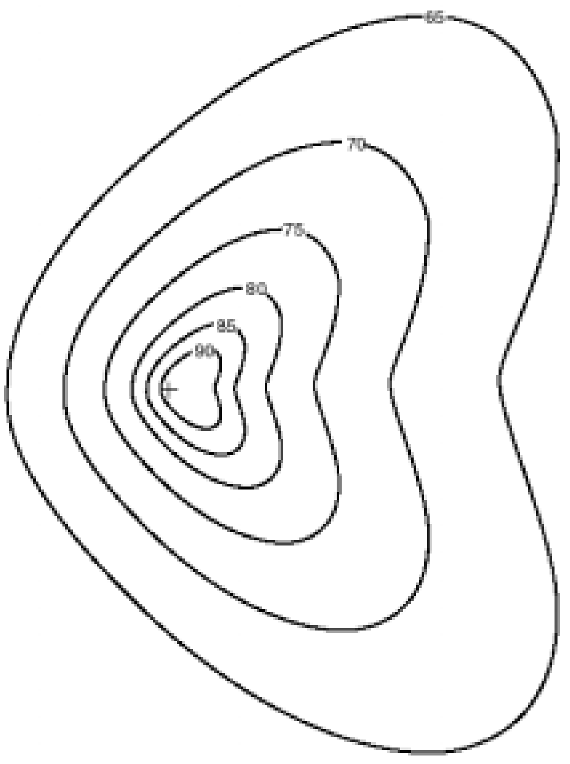
Noise tends to be more intrusive at night than during the day. This effect is accounted for by applying a 10-dB penalty to events that occur after 10 p.m. and before 7 a.m. If L_{eq} is computed over a 24-hour period with this nighttime penalty applied, the result is the day-night average sound level (L_{dn} or DNL). L_{dn} is the community noise metric recommended by the U.S. Environmental Protection Agency (U.S. Environmental Protection Agency, 1972) and has been adopted by most federal agencies (Federal Interagency Committee on Noise, 1992). It has been well established that L_{dn} correlates well with community response to noise (Schultz, 1978; Finegold, 1994).

The state of California quantifies noise by Community Noise Equivalent Level (CNEL). This metric is similar to L_{dn} except that a penalty of 5 dB is applied to sounds that occur in the evening, after 7:00 p.m. and before 10:00 p.m.

It was noted earlier that, for impulsive sounds, C-weighting is more appropriate than A-weighting. The day-night average sound level can be computed for C-weighted noise, and is denoted L_{Cdn} or CDNL. This procedure has been standardized, and impact-interpretive criteria similar to those for L_{dn} have been developed (CHABA, 1981).

1.2 Rocket Noise

Rocket noise is generated primarily by mixing high-speed rocket exhaust flow with the atmosphere. Noise is also generated by fuel and oxidizer burning in the combustion chamber, shock waves and turbulence within the exhaust flow, and sometimes, burning of excess fuel in the exhaust flow. The result is a high-amplitude continuous sound, directed generally behind the vehicle. Figure U-2 shows the typical pattern of noise behind a rocket engine. In this illustration, the exhaust flow is horizontal, directed toward the east (right). This depiction corresponds to a horizontally mounted rocket (common in ground testing of engines) or a rocket on a launch pad where a deflector has turned the exhaust sideways. Noise is shown as contours of various decibel values. All points inside a given contour experience noise equal to or higher than that contour value. The pattern is fairly uniform in the forward direction (toward the left in this figure), has high-amplitude lobes at around 45 degrees from the flow direction (the angle of the lobes varies), and has a minimum directly in line with the exhaust.



EXPLANATION

—80— Noise Contour (decibels)

Not to Scale

Nominal Noise Contours for Horizontal Firing Rocket Engine

Figure U-2

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When a rocket is launched, after a short time, it is above the ground and the exhaust is clear of the ground and any deflectors. When the rocket is climbing vertically, the noise contours on the ground are circular. As the rocket continues to climb, it would pitch over in its launch azimuth. The contours would be distorted in this direction, sometimes becoming stretched and sometimes broadened, depending on details of the particular vehicle and launch. Figure U-3 shows typical noise contours for a launch toward the east. The trajectory is indicated, and the launch point is at the center of the innermost contours.

In Figure U-2, as long as the rocket is on the ground the noise is constant, and the contours show what would be measured at any time while the engine is firing. For a launch, as in Figure U-3, noise is not constant. It is loudest shortly after launch, then diminishes as the rocket climbs. The noise is still considered to be continuous because it varies over periods of seconds or minutes. Contours of AWSPL or OSPL are drawn to represent the maximum levels that occur at each point during the entire launch. These levels may only occur for a few seconds and do not occur at the same time at each point, but are the most important (i.e., worst-case) quantity for assessing launch noise impact.

In this assessment, contours (similar to Figure U-3) are presented for launch noise. Because contours are approximately circular, it is often adequate to summarize noise by giving the sound levels at a few distances from the launch site.

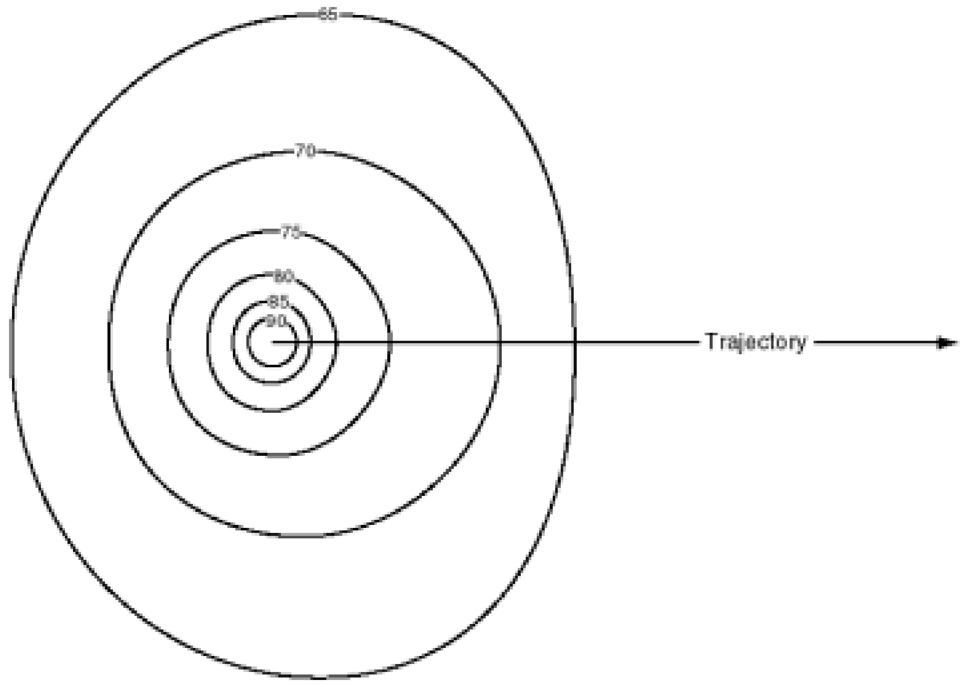
1.3 Sonic Booms

When launch vehicles reach supersonic speed, they generate sonic booms. Sonic booms are the shock waves resulting from the displacement of air in supersonic flight. They differ from other sounds in that they are impulsive and brief.

Figure U-4 is a sketch of a sonic boom for the simple case of an aircraft in steady-level flight. The aircraft is flying to the left. The sonic boom consists of two shock waves: one generally associated with the front of the aircraft, and one with the rear. They are connected by a linear expansion. The pressure-time signature at the ground resembles the letter “N” and is referred to as an N-wave. It is described by the peak overpressure of each shock, and the time between the shocks. Usually the time between shocks does not affect impact, so sonic booms are most commonly described by their peak overpressures.

In Figure U-4, the sonic boom is generated continuously as the aircraft flies, and this illustration is from the perspective of moving with the aircraft. At a location on the ground, however, the boom exists briefly as the N-wave passes over that point. It is common to refer to the footprint of a steady-flight sonic boom as a “carpet,” consisting of a “carpet” of area on the ground that is swept out as the aircraft flies along its path. N-wave booms are often referred to as “carpet booms.”

Figure U-5 shows an aircraft sonic boom from a different perspective. The aircraft is flying to the right, and the cone to the left is a three-dimensional version of the shocks in Figure U-4. It is the boom as it exists at a given time. It is generated over a period of time, with the boom at the ground having been created at an earlier time. The sonic boom energy generated at a given time propagates forward of the aircraft, along a cone similar to the one projected to the right in Figure U-5. It reaches the ground in a forward-facing crescent, as indicated in the figure.



EXPLANATION

—80— Noise Contour (decibels)

Nominal Noise Contours for Ascent of a Launch Vehicle

Figure U-3

Not to Scale

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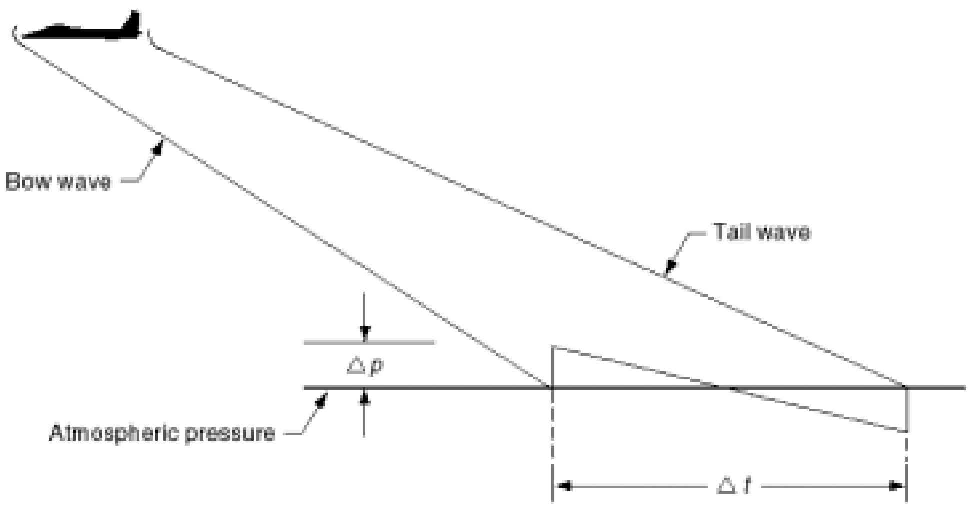

Sonic Boom From an Aircraft in Level Flight

Figure U-4

Not to Scale

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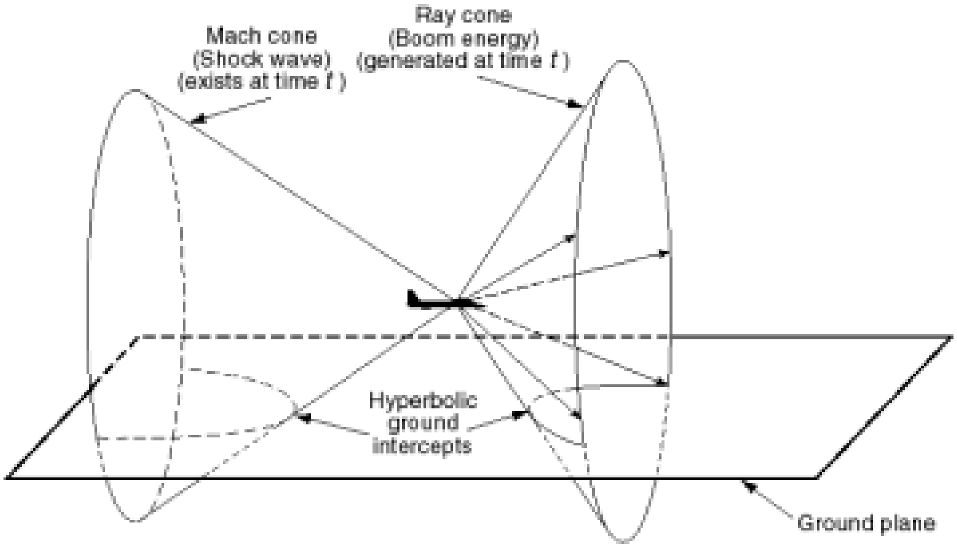

Sonic Boom in Level Flight, Showing Shock Wave and Propogation of Boom Energy

Figure U-5

Not to Scale

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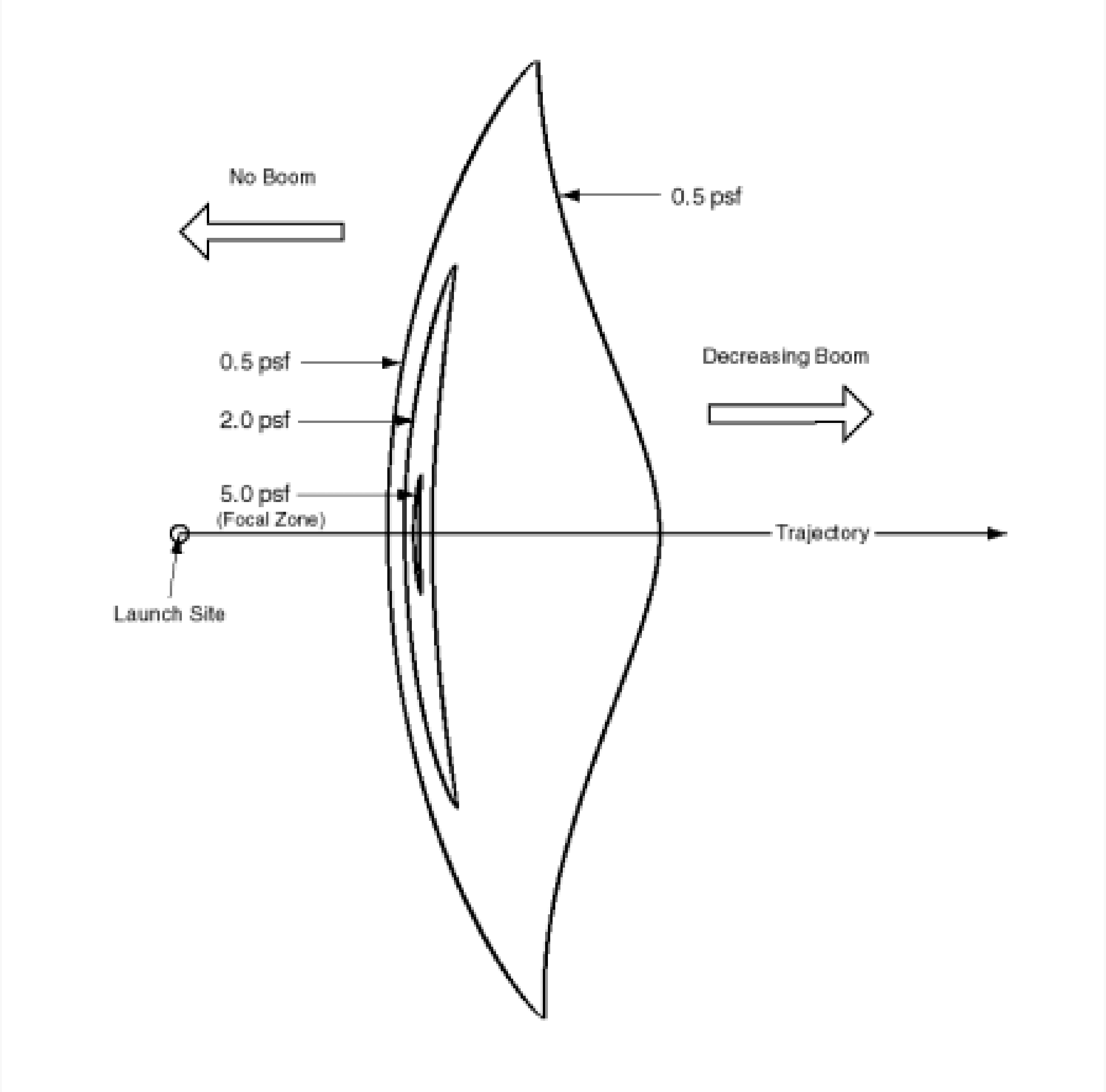
Sonic booms from launch vehicles differ from those sketched in Figures U-4 and U-5 in two ways. First, launch vehicles begin their flight vertically, then slowly pitch over toward the horizontal. Second, launch vehicles accelerate, so speed is continuously changing as they ascend. The cone angles shown in Figures U-4 and U-5 change with speed. Shock waves are generated only after the vehicle exceeds Mach 1, and the waves reach the ground as sonic booms only after the vehicle has pitched over and reached a particular Mach number. Figure U-6 shows nominal sonic boom noise contours (not to scale) from a launch vehicle. The contour values represent pressure in pounds per square foot (psf), the unit most commonly used. The launch site is noted on the figure, and the launch direction is to the right. As with the noise contours shown in Figures U-2 and U-3, regions within each contour experience overpressures equal to or greater than that denoted for the contour. Also, the contours denote the peak pressure that occurs at each point over the course of the launch and does not represent noise at any one time. The sonic boom event at each position is brief, as noted in the preceding paragraph.

Because sonic boom is not generated until the vehicle becomes supersonic sometime after launch, the launch site itself does not experience a sonic boom. The crescent shape of the contours reflects this “after-launch” nature of sonic boom: the entire boom footprint is downtrack, and portions of the footprint to the side of the trajectory (up and down in the figure) are farther downtrack. This pattern is similar to the forward-facing crescent seen in the right half of Figure U-5. There is no boom to the left of the contours shown, and the boom diminishes rapidly farther downtrack, to the right of the contours.

The left edge of the contours shown in Figure U-6 is a special region. Because the vehicle is accelerating, sonic boom energy tends to be more concentrated than if it were in steady flight. The left edge is where the boom first reaches the ground, and the concentration is highest there. There is a narrow “focus boom” or “superboom” region, usually less than 100 yards where the sonic boom amplitude is highest. The boom signature is also distorted into what is referred to as a “U-wave.”

Figure U-7 shows time histories (pressure versus time) for N-wave carpet booms and U-wave focus booms. Each consists of a pair of shock waves connected by a linear expansion (N-wave) or a U-shaped curve (U-wave). Each type of boom is well described by its peak overpressure in psf, and its duration in milliseconds (msec). Duration tends to have a minor effect on impact, so the peak pressure is all that is normally required.

The 0.5-psf contour shown in Figure U-6, although not to scale, has a shape similar to an actual low-overpressure sonic boom contour. The two higher contours, 2.0 and 5.0 psf, are considerably distorted from typical actual contours. The crescent shape is correct, and their width across the trajectory (i.e., vertical height on this figure) relative to the 0.5-psf contour is approximately correct. Their width and position in the direction along the trajectory is greatly exaggerated. It is typical that the left edge of these higher contours would be very close to the left edge of the 0.5-psf contour, and would not appear as a distinct line when plotted to any reasonable scale. The right edge of these contours would also be much closer to the left than shown, and would often not appear as distinct lines. The focus boom region is within the 0.5-psf contour.



EXPLANATION

psf	Pounds per square foot

Nominal Sonic Boom Contours for Ascent of a Launch Vehicle

Figure U-6

Not to Scale

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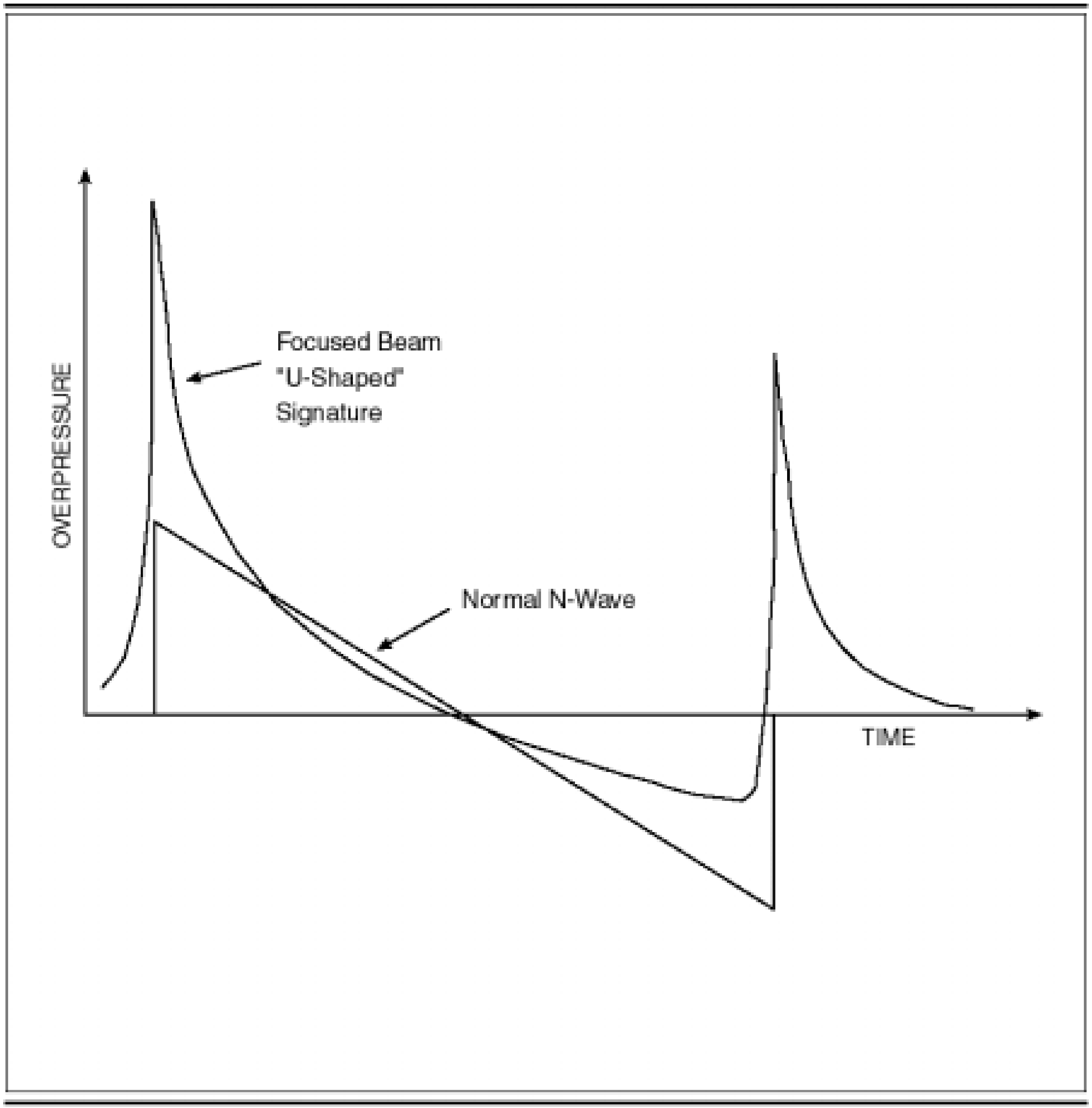

Focused U-Wave and Unfocused N-Wave Boom Signatures

Figure U-7

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For assessment of impact via L_{Cdn}, as discussed in Section 1.1, the peak pressure is related in a simple way to CSEL, from which L_{Cdn} can be constructed. The peak pressure P (psf) is converted to the peak level (L_{pk}) dB by the relation:

$$L_{pk} = 127.6 + 20 \log_{10} P$$

CSEL is then given by Plotkin (1993):

$$\text{CSEL} = L_{pk} - 26 \qquad \text{(N-wave)}$$

$$\text{CSEL} = L_{pk} - 29 \qquad \text{(U-wave)}$$

Most sonic boom literature describes booms in terms of overpressure psf. This assessment adheres to that convention. The above relations give simple conversions to decibels should those units be of interest.

2.0 Noise Effects

2.1 Annoyance

Studies of community annoyance from numerous types of environmental noise show that L_{dn} is the best measure of impact. Schultz (1978) showed a consistent relationship between L_{dn} and annoyance. This relationship, referred to as the “Schultz curve,” has been reaffirmed and updated over the years (Fidell, 1991; Finegold, 1994). Figure U-8 shows the current version of the Schultz curve.

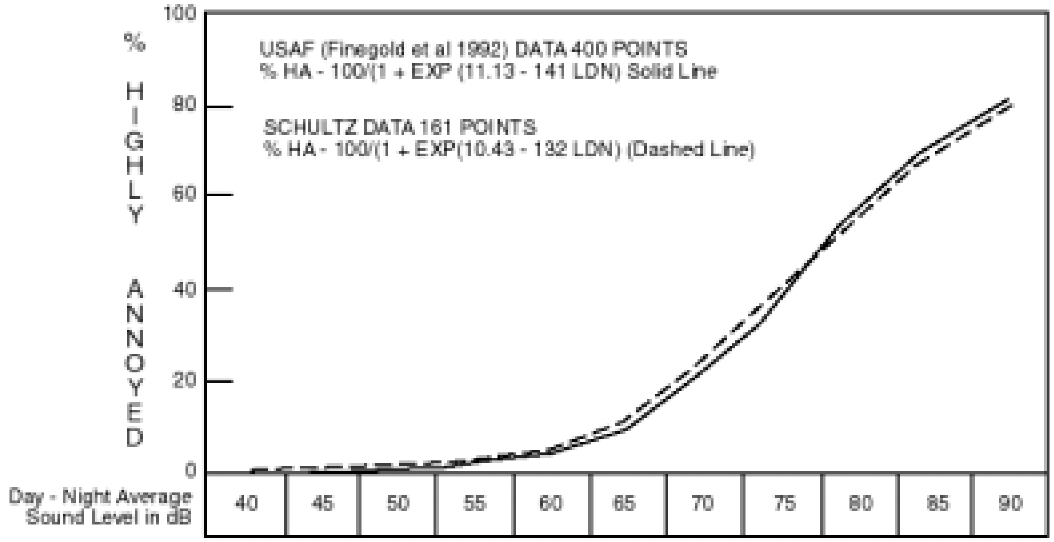
A limitation of the Schultz curve is that it is based on long-term exposure to noise. EELV program launches would be relatively infrequent, so analysis in the current study examines individual noise levels rather than L_{dn} compared to the Schultz curve.

Some time ago, an L_{dn} of 55 dB or less was identified as a threshold below which adverse impacts to noise are not expected (U.S. Environmental Protection Agency, 1972). It can be seen from Figure U-8 that this is a region where a small percentage of people are highly annoyed. An L_{dn} of 65 dB is widely accepted as a level above which some adverse impact should be expected (Federal Interagency Committee on Noise, 1992), and Figure U-8 demonstrates that about 15 percent of people are highly annoyed at that level.

2.2 Speech Interference

Conversational speech is in the 60- to 65-dB range, and interference with this can occur when noise enters or exceeds this range. Speech interference is one of the primary causes of annoyance. The Schultz curve incorporates the aggregate effect of speech interference on noise impact.

Because EELV program launches would be infrequent, and noise would last for only a few minutes, speech interference is not expected to be a major issue.



Calculated % HA Points		40	45	50	55	60	65	70	75	80	85	90
	USAF	0.41	0.831	1.66	3.31	6.48	12.29	2.21	36.47	53.47	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

Community Response to Noise

Figure U-8

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2.3 Sleep Interference

Sleep interference is commonly believed to represent a significant noise impact. The 10-dB nighttime penalty in L_{dn} is based primarily on sleep interference. Recent studies, however, show that sleep interference is much less than had been previously believed (Pearsons, 1989; Ollerhead, 1992).

Traditional studies of sleep disturbance indicate that interference can occur at levels as low as 45 dB. Data indicate that at an indoor SEL of 70 dB, approximately 20 percent of people would awaken (Federal Interagency Committee on Noise, 1992). Assuming a nominal outdoor-to-indoor noise reduction of 20 dB, these two measurements (45 dB and 70 dB) correspond to outdoor sound exposure levels of 65 dB and 90 dB, respectively. Note that the awakening threshold is comparable to the threshold of outdoor speech interference.

2.4 Task Interference

As a result of startle effects, some task interference may occur from sonic booms. High levels of rocket noise may cause some task interference close to the launch sites. It is difficult to estimate degrees of task interference, because such interference is highly dependent on specific tasks. Startle from sonic booms is often stated as a concern, but there are no credible reported incidents of harm from sonic boom startle. Task interference from rocket noise is expected to occur at higher noise levels than speech interference.

2.5 Hearing Loss

Federal Occupational Safety and Health Administration (OSHA) guidelines (Title 29 CFR 1910.95) specify maximum noise levels to which workers may be exposed on a regular basis without hearing protection. Pertinent limits are a maximum of 115 dBA for up to 15 minutes per day, and unweighted impulsive noise of up to 140 dB. Exceeding these levels on a daily basis over a working career is likely to lead to hearing impairment. These levels are conservative for evaluating potential adverse effects from occasional noise events.

2.6 Health

Nonauditory effects of long-term noise exposure, where noise may act as a risk factor, have never been found at levels below federal guidelines established to protect against hearing loss. Most studies attempting to clarify such health effects found that noise exposure levels established for hearing protection would also protect against nonauditory health effects (von Gierke, 1990). There are some studies in the literature that claim adverse effects at lower levels, but these results have generally not been reproducible.

2.7 Structures

2.7.1 Launch Noise

Damage to buildings and facilities from noise is generally caused by low-frequency sounds. The probability of structural damage claims has been found to be proportional to the intensity of the low-frequency sound. Damage claim experience (Guest and Sloane, 1972) suggests that one claim in 10,000 households is expected at a level of 103 dB, one in 1,000 households at 111 dB, and one in 100 households at 119 dB.

Figure U-9 shows criteria for damage to residential facilities (Sutherland, 1968) and compares them to launch noise spectra that could occur a few kilometers from the launch pad. These data show that noise-induced damage to off-base property would be minimal.

2.7.2 Sonic Boom

Sonic booms are commonly associated with structural damage. Most damage claims are for brittle objects, such as glass and plaster. Table U-1 summarizes the threshold of damage that might be expected at various overpressures. There is a large degree of variability in damage experience, and much damage depends on the pre-existing condition of a structure. Breakage data for glass, for example, spans a range of two to three orders of magnitude at a given overpressure. While glass can suffer damage at low overpressures (shown in Table U-1) laboratory tests of glass (White, 1972) have shown that properly installed window glass would not break at overpressures below 10 psf, even when subjected to repeated booms.

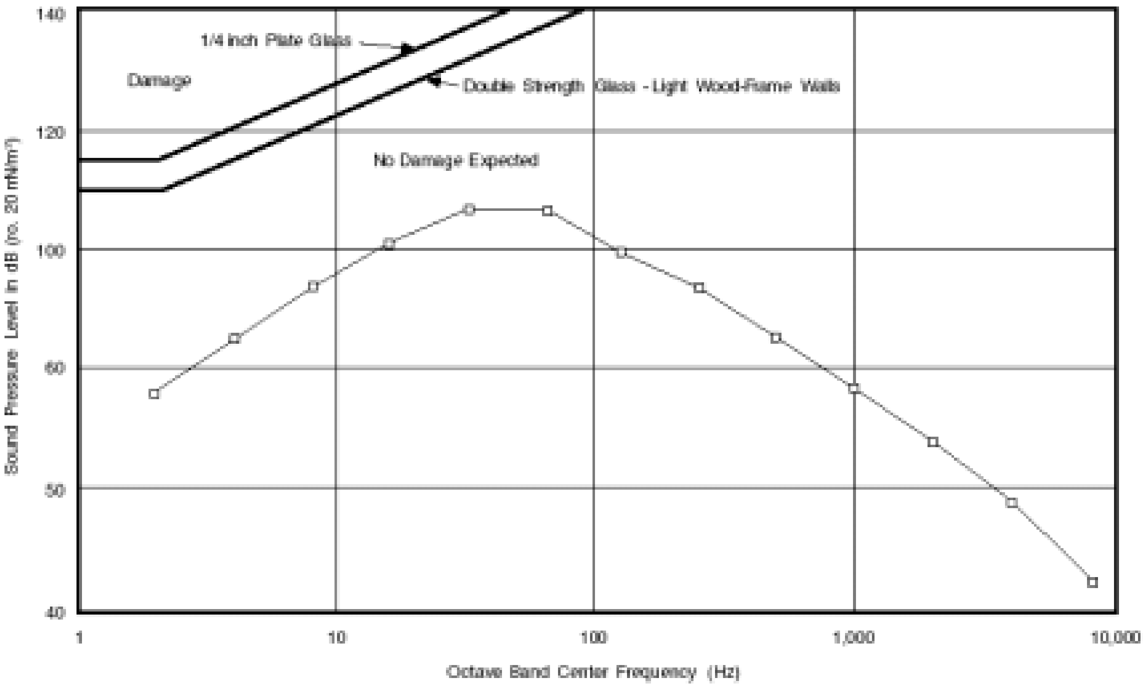
Most of the area exposed to sonic booms would be below 2 psf, where there is a small probability of damage. Additionally, the BLAST over-pressure program will be run for all launches for the proposed action, to determine the risk level to individuals due to glass breakage resulting from a vehicle explosion on or near the launch pad. Boom amplitude would exceed this in limited areas associated with focusing, with maximum overpressures in the 6- to 8-psf range. Because of the limited area involved in a focal zone, adverse impact would depend on the relation of the focal zones to sensitive receptors.

2.8 Wildlife

The response to sonic booms or other sudden disturbances is similar among many species (Moller, 1978). Sudden and unfamiliar sounds usually act as an alarm and trigger a “fight-or-flight” startle reaction. This sudden panic response may cause wildlife to injure themselves or their young, but this is usually the result of the noise in association with the appearance of something perceived by the animals as a pursuit threat, such as a low-flying aircraft. Launch noise is not expected to cause more than a temporary startle-response, because the “pursuit” would not be present. Any loss or injury as a result of this startle response would be incidental, and not a population-wide effect. Animals control their movements to minimize risk. Loss rates have varied greatly in the few documented cases of injury or loss: mammals and raptors appear to have little susceptibility to those losses; the most significant losses have been observed among waterfowl. Panic responses typically habituate quickly and completely with fewer than five exposures (Bowles, 1997).

During a Titan II launch from SLC-4 at Vandenberg AFB, all snowy plovers flushed and settled in a somewhat different flock configuration. One-half mile south of the Santa Ynez River, no discernible response occurred during launch. The snowy plovers stood from roost sites and walked one meter from original roosting position. The reaction exhibited resembled the response to a perceived predator threat, including a return to normal behavior when the perceived threat had passed (Read, 1996a,b).

The startling effect of a sonic boom can be stressful to an animal. This reaction to stress causes physiological changes in the neural and endocrine systems, including increased blood pressure and higher levels of available glucose and corticosteroids in the bloodstream. Continued disturbances and prolonged exposure to severe stress may deplete nutrients available to the animal.



Criteria for Noise Damage to Residential Structures and Typical Off-Base Launch Noise Spectrum

Figure U-9

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TABLE U-1
Possible Damage to Structures From Sonic Booms

Sonic Boom Overpressure Nominal (psf)	Type of Damage	Item Affected
0.5-2	Cracks in plaster	Fine; extension of existing; more in ceilings; over door frames; between some plaster boards.
	Cracks in glass	Rarely shattered; either partial or extension of existing.
	Damage to roof	Slippage of existing loose tiles/slates; sometimes new cracking of old slates at nail hole.
	Damage to outside walls	Existing cracks in stucco extended.
	Bric-a-brac	Those carefully balanced or on edges can fall; fine glass, e.g., large goblets, can fall and break.
	Other	Dust falls in chimneys.
2-4	Glass, plaster, roofs, ceilings	Failures show that would have been difficult to forecast in terms of their existing localized condition. Nominally in good condition.
4-10	Glass	Regular failures within a population of well-installed glass; industrial as well as domestic greenhouses.
	Plaster	Partial ceiling collapse of good plaster; complete collapse of very new, incompletely cured, or very old plaster.
	Roofs	High probability rate of failure in nominally good state, slurry-wash; some chance of failures in tiles on modern roofs; light roofs (bungalow) or large area can move bodily.
	Walls (out)	Old, free standing, in fairly good condition; can collapse.
	Walls (in)	Interior walls known to move at 10 psf.
Greater than 10	Glass	Some good glass would fail regularly to sonic booms from the same direction. Glass with existing faults could shatter and fly. Large window frames move.
	Plaster	Most plaster affected.
	Ceilings	Plaster boards displaced by nail popping.
	Roofs	Most slate/slurry roofs affected, some badly; large roofs having good tile can be affected; some roofs bodily displaced causing gable-end and wall-plate cracks; domestic chimneys dislodged if not in good condition.
	Walls	Interior walls can move even if carrying fittings such as hand basins or taps; secondary damage from water leakage.
	Bric-a-brac	Some nominally secure items can fall; e.g., large pictures, especially if fixed to party walls.

Source: Haber and Nakaki, 1989.

Both physiological and behavioral responses to sonic booms have been examined among California pinnipeds (Manci, et al., 1988). The physiological study demonstrated recognizable short-lived changes in hearing sensitivity as a result of minimum sonic boom overpressures. Longer temporary hearing losses are likely to occur for exposures greater than those tested (Manci, et al., 1988).

Behaviorally, harbor seals, California sea lions, northern fur seals, and Guadalupe fur seals at the Channel Islands would react to sonic booms of any intensity, and many would move rapidly into the water, depending on the season and amplitude of the boom. However, any observed response is usually short in duration. Elephant seals would startle in response to sonic booms of low intensity, but they resume normal behavior within a few minutes of the disturbance (Manci, et al., 1988).

A launch effect of 127.4 dB (108.1 dBA) caused 20 of 23 of the Purisima Point harbor seals to flee into the water, and only 3 returned after 2.5 hours. At Rocky Point, 20 of 74 harbor seals fled into the water during a 103.9-dB (80-dBA) launch event, returning after 30 minutes. Another launch (98.7 to 101.8 dBA) caused almost all Rocky Point harbor seals ashore to flee into the water, after which 75 percent returned within 90 minutes (Tetra Tech, Inc., 1997).

Harbor seals, California sea lions, northern fur seals, and Guadalupe fur seals at the Channel Islands would startle in response to sonic booms of any intensity, and many would move rapidly into the water, depending on the season and amplitude of the boom, but any observed response is usually short-lived. Elephant seals would startle in response to sonic booms of low intensity, but they resume normal behavior within a few minutes of the disturbance (Manci, et al., 1988).

Manatees are relatively unresponsive to human-generated noise to the point that they are often suspected of being deaf to oncoming boats (although their hearing is actually similar to that of pinnipeds) (Bullock, et al., 1980). Since manatees spend most of their time below the surface, and since they do not startle readily, no effect of aircraft or launch vehicle overflights on manatees would be expected (Bowles, et al., 1991).

The effect of launch noises on cetaceans appears to be somewhat attenuated by the air/water interface. The cetacean fauna in the area have been subjected to sonic booms from military aircraft for many years without apparent adverse effects (Tetra Tech, Inc., 1997).

Raptor response to sonic boom while nesting was investigated through the use of simulated booms in natural conditions. Response to sonic boom was fairly minimal (Ellis, 1991). The sonic booms generated for response testing were equivalent to impulse noises generated by supersonic jets in the medium- to high-altitude range (2,000 to 3,000 miles). There was a total of seven raptor species tested, including 84 individuals in various life stages. Of the individuals observed during sonic booms, 65 responses were insignificant. Adult response to the sonic boom usually resulted in flushing from the nest, although incubating or brooding adults never left the nesting area. Reactions among species did have some variation. The reproductive rates for the tested sites were at or above normal for both years of testing. Heart rate response to sonic booms were measured using captive peregrine falcons. Heart rates after sonic booms were at or below a heart rate level of a falcon returning from flight (Ellis, et al., 1991). In a different study on adult peregrine falcons, the startle response was found to cause egg breakage of already thin eggshells (residual dichlorodiphenyltrichloroethane [DDT] effects) or cause young close to fledgling age to fledge prematurely, thus placing them at a particularly high risk of mortality (Read, 1996a). Peregrine falcons at the early nesting phase are not adversely impacted by Titan IV launches because the chicks are expected to crouch safely down in their nests rather than move toward the edge of the ledge (Read, 1996a).

A huge sooty tern nesting failure that occurred in the southern Florida Dry Tortugas colony in 1969 may have been a result of sonic booms that occurred on a daily basis (Austin, et al., 1970). Birds had been observed to react to sonic booms in previous seasons with a panic flight, circling over the island momentarily, and then usually settling down on their eggs again. Upon review, the nesting failure was attributed more likely to the interruption of the incubation period and from nest abandonment.

3.0 Noise Modeling

3.1 Launch Noise

On-pad and in-flight rocket noise was computed using the RNOISE model (Plotkin, 1997). Rocket noise prediction via this model consists of the following elements:

1. The total sound power output, spectral content, and directivity are based on the in-flight noise model of Sutherland (1993). Noise emission is a function of thrust, nozzle exit gas velocity, nozzle exit diameter, and exhaust gas properties.

   Propagation from the vehicle to the ground accounts for Doppler shift, absorption of sound by the atmosphere (American National Standards Institute, 1978), inverse square law spreading, and attenuation of sound by the ground (Chien and Soroka, 1980). A semi-hard ground surface (1,000 mks rayls) was assumed.

2. One-third spectral levels were computed at the ground, for every flight trajectory point, on a grid of 3,721 points. ASEL and maximum A-weighted and overall sound levels were then derived from the results at each grid point.

   The computed noise levels were then depicted as contours of equal level.

3.2 Sonic Boom

Sonic boom was computed using the U.S. Air Force’s PCBoom3 software (Plotkin, 1996). This is a full-ray tracing model. Details of sonic boom theory are presented by Plotkin (1989) and Maglieri and Plotkin (1991). The specific approach to EELV program sonic boom modeling included the following elements:

1. Trajectories provided by the vehicle manufacturers were converted into PCBoom3 TRJ format using PCBoom3’s TRAJ2TRJ utility. This utility generated required higher derivatives, as well as converting file formats.

2. Vehicle F-functions were calculated using the method of Carlson (1978). Area distributions were obtained from vehicle drawings. The shape factors computed were used to obtain nominal N-wave F-functions.

3. The F-function associated with the plume was obtained using a combination of the Universal Plume Model (Jarvinen and Hill, 1970) and Tiegerman's (1975) hypersonic boom theory.
4. Ray tracing and signature evolution were computed by integration of the eiconal and Thomas's (1972) wave parameter method.
5. Focal zones were detected from the ray geometry, and focus signatures computed by applying Gill and Seebass's (1975) numerical solution.

The resultant sonic boom calculations were depicted as contours of constant overpressure (psf).

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