2.0 BASIC CONCEPTS

2.1 Sound Exposure Metrics

A-Weighted Sound Level

The normal human ear can detect sound frequencies ranging from about 20 Hz to about 15,000 Hz. Hertz is the unit used to indicate frequency and is equal to the number of cycles per second. Low-pitched sounds have low frequencies and high-pitched sounds have high frequencies. People do not hear all sounds over this wide range of frequencies equally well, however. The human ear is most sensitive to sounds in the 1000 to 4000 Hz range.

In order to reflect the differences in hearing sensitivity to different frequencies, sound levels are usually stated in terms of the A-weighted audibility scale. When a sound spectrum is A-weighted, sound levels in the 1000 to 4000 Hz frequency range are *increased* by a specified amount to account for the fact that the ear perceives them as louder compared to other frequencies. Similarly, the loudness at lower frequencies and at much higher frequencies is *reduced* because the ear is less sensitive in those regions. The A–weighting curve in Figure 2-1 shows how much is added to, or subtracted from, a sound level depending on the frequency. For example, at 250 Hz a value of 8.6 dB would be subtracted from a sound level to get the A–weighted one-third octave level. The unit of measure for all noise levels is the decibel (dB) and A–weighted levels are indicated by the unit "dBA".

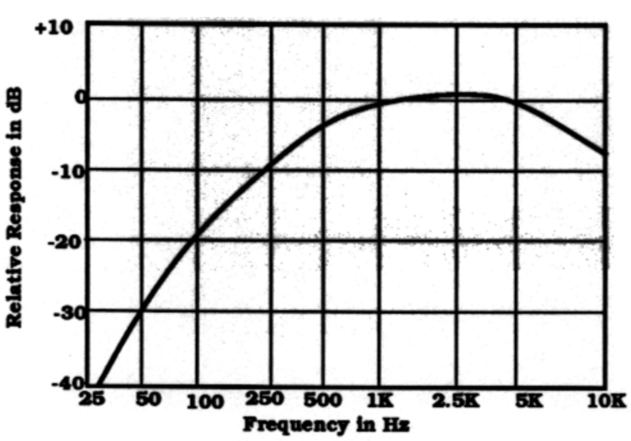

Figure 2.1. A-Weighting Versus Frequency.

Day-Night Average Sound Level (DNL) and Noise Contours

Aircraft noise exposure in a community is usually described in terms of noise contour maps. These indicate bands or zones around airfields where the average noise level can be expected to fall within the ranges specified by the contour lines. Contour maps typically show continuous lines of equal exposure drawn in 5 dB increments. Figure 2-2 shows a sample contour map.

The acoustic metric used is the Day-Night Average Sound Level (DNL or L_{dn}). This is a cumulative measure of the noise exposure during a 24–hour day. A 10 dB penalty is added to noise events occurring between 10:00 p.m. and 7:00 a.m. to reflect their greater intrusiveness and potential for disturbing sleep. The DNL is the result of averaging the A–weighted sound pressure level over 24 hours for aircraft activities throughout a year. This gives an indication of the long-term noise exposure for the community. DNL has proven to be a very reliable predictor of community reaction to noise intrusion.

Noise is generally identified as a problem for noise zones at and above DNL 65 dB. Residential land uses are considered unacceptable when the DNL is 75 dB or greater.

Sound Exposure Level (SEL), the Single-Event Metric

The Sound Exposure Level, SEL, is a single-event sound level often used in addition to DNL to evaluate noise exposure. It measures the total audible energy in a single flyover and presents it as though it took place in one second. Normalizing the sound energy to one second makes it possible to compare events that vary in duration.

Using the SEL gives a better measure of the intrusiveness of individual aircraft noise events as opposed to the long-term exposure which DNL predicts. Both SEL and DNL are derived from A–weighted sound levels. The difference between them is basically one of time averaging. DNL expresses the impact of all flights throughout the day. SEL, on the other hand, focuses on the effect of a single event and shortens the exposure time to one second. Both SEL and DNL are usually available in the form of mapped noise exposure contours. Because SEL expresses sound energy in a short timeframe, while DNL averages it out over many hours, SEL numbers are higher than DNL for the same location.

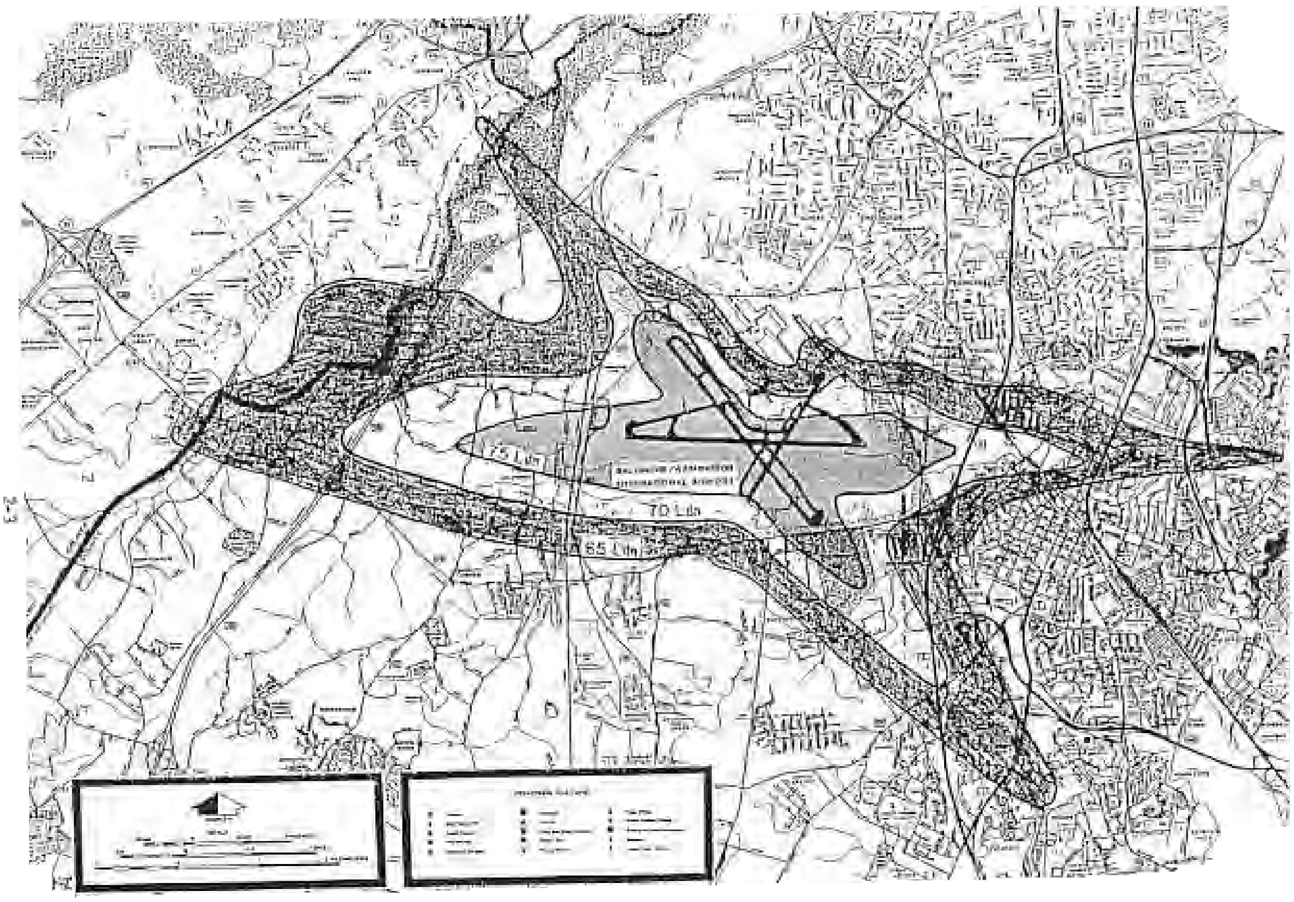

Figure 2-2. Example of Noise Contours at Baltimore/Washington International Airport.

Also, since DNL is a long-term average it cannot be measured directly the way SEL can. SEL measurements are useful for determining the existing and improved noise reduction in a dwelling. These measurements are discussed in Section 3.3.

2.2 Noise Intrusion From Aircraft Operations

Interference With Activities

The problem of aircraft noise has been recognized and studied in this country since the 1950s. While advances have been made in mitigating aircraft noise impact, there is a continuing need to safeguard the public health and welfare as well as to ensure the safety and efficiency of aircraft operations. Opinion surveys indicate that interference with telephone usage, listening to television and radio, and conversation invoke the most complaints. While residents often notice improvements in their ability to fall asleep and to concentrate after their home has been insulated for sound, these are not the activities they complain the most about.

Fears of permanent hearing damage from flyovers have been shown to be unfounded. A large number of studies on the physical, mental, and emotional health effects of aircraft noise exposure have led to the general conclusion that residences near airports are not exposed to high enough sound levels to warrant concern. The principal effect of aircraft noise on airfield neighbors is annoyance, caused by interference with daily activities.

Noise Characteristics

Noise intrusion from aircraft activities is perceived as more disturbing than other kinds of noise because of two characteristics. Unlike many other community noise sources which tend to be fairly constant, aircraft noise consists of sporadic individual noise events with a distinct rise and fall pattern. People do not, in general, respond to these events as just another component of the "background noise" of their day-to-day lives. Each individual flyover event remains recognizable and disturbing.

The second quality that makes aircraft noise more intrusive is its higher level, or loudness. The noise level experienced at a particular dwelling will depend on its location relative to the aircraft flight paths and the mode of ongoing aircraft operations (arrivals or departures).

Aircraft Sound Spectrum

The noise produced by modern aircraft contains acoustical energy over a wide frequency range. The audible noise which results varies from a very low-frequency "rumble" to a very high-frequency "whine", depending on the aircraft type and the operation performed (takeoff, landing, or ground run-up). Low-frequency noise (below 500 Hz) penetrates walls, roofs, doors, and windows much more efficiently than does high-frequency noise. Higher frequencies (above 1000 Hz), however, are carried through cracks and vents better. Also, people hear higher frequency sound better, the human ear being more sensitive above 1000 Hz than below.

Each noise source generates a characteristic sound spectrum. This spectrum can be plotted showing the noise level as a function of frequency. Aircraft noise differs somewhat from other types of community noise. It is important to identify the spectral characteristics of the noise that sound insulation is protecting against. Most materials and construction methods are more effective at insulating in one part of the frequency spectrum than in others. Knowing the noise characteristics helps to choose the best materials for insulation.

Most of the sound energy from aircraft operations is found at lower frequencies. While this energy is below the most sensitive region of people's hearing range, it can be heard well enough to be a problem and it causes disturbing structural vibration in a dwelling. Section 2.5 discusses the process by which sound gets transmitted into a dwelling interior.

2.3 Sound Insulation Metrics

Several metrics have been developed for discussing and specifying sound insulation performance. Each term differs from the others in important ways, but all refer to the ability to inhibit sound transmission. Several nationally (and internationally) recognized organizations have developed standards and specifications for evaluating these quantities. The organizations are identified in this section, and the Glossary (Appendix E) and the List of Organizations (Appendix G) provide more information on them. Standards and specifications are revised from time to time and it is important to keep abreast of these changes. Current versions can be obtained directly from the organizations themselves.

Of the descriptors that we are concerned with, two are determined by laboratory testing procedures: Sound Transmission Loss (TL) and Sound Transmission Class (STC). The Exterior Wall Rating (EWR) uses acoustical analysis based on TL. The others – Noise Reduction (NR) and Noise Level Reduction (NLR) – are determined by field testing of actual built systems. In general, a construction method or component will have a lower performance rating when tested under realistic field conditions than when tested in a laboratory. This is because sound-flanking paths, which can be minimized in a testing laboratory, are not as easily controlled in actual construction. Flanking refers to sound bypassing a wall – through crawlspaces, vents, rigid edge connections, and other means. Also, it is difficult to measure noise only through an isolated, single element such as a window, section of wall, or door in a field installation.

*Sound Transmission Loss (TL)**

This is the physical measure which describes the sound insulation value of a built construction system or component. It is a measure, on a logarithmic scale, of the ratio of the acoustic sound power incident on the tested piece to the acoustic sound power transmitted through it. The TL is expressed in decibels (dB). Generally, TL is measured as a function of frequency in one-third octave frequency bands. The higher the sound insulation, the less sound will be transmitted, resulting in a higher TL value. Values of TL are determined in acoustical laboratories under controlled testing methods prescribed by the American Society for Testing and Materials (ASTM).

*Sound Transmission Class (STC)***

Since working with a series of one-third octave TL measurements can be cumbersome, a single-number descriptor based on the one-third octave TL values has been developed. This rating method is called the Sound Transmission Class (STC). Like TL, the higher the STC rating for a construction method or component, the higher the sound insulation. Originally, STC ratings were developed as a single-number descriptor for the TL of interior office walls for typical office noise and speech spectra. Now, they are used, often incorrectly, for exterior walls as well. Most acoustical materials and components are commonly specified in terms of their STC rating.

*Exterior Wall Rating (EWR)**

EWR is a single-number rating for exterior building elements (such as walls, windows, doors, etc.) and represents the effective sound transmission loss capability, in decibels, of each element. It differs from STC rating in that it is based on aircraft noise rather than office noise spectra. For this reason, EWR is superior to STC for describing the sound-insulating properties of exterior wall elements exposed to aircraft noise. The EWR concept was developed by Wyle Laboratories and has been used extensively in studies of residential sound insulation. It is conceptually similar to the STC rating method. Like TL and STC, the higher the EWR value, the better the noise reduction.

Commercial products are usually specified in terms of STC. Therefore, when designing dwelling modifications, required EWR values for building elements are accompanied by the equivalent STC value, for specification purposes.

*Noise Reduction (NR)****

The quantitative measure of the sound isolation between spaces is called Noise Reduction (NR). The NR between two spaces, such as from the exterior to the interior of a dwelling, depends on the TL of the various components in the separating wall, the area of the separating wall, and the acoustical absorption in the receiving room. This value takes more into account than just the sound transmission characteristics of the wall material. Generally, values of NR are determined in one-third octave bands. A higher NR gives a lower noise level in the receiving room, indicating greater noise insulation.

Noise Level Reduction (NLR)

NLR is used to describe the reduction of environmental noise sources, such as aircraft. It is a single-number metric based on values of A-weighted noise reduction (NR). The greater the sound insulation in a wall, the lower the noise level in the receiving room, giving a higher NLR. The NLR is useful because it is a simpler metric to

* Typical tests to determine TL are described in ASTM E-90.

** STC is described in ASTM E-413.

*** Values of NR can be determined in built constructions under controlled field conditions described in ASTM E-336 and E-966.

use than NR; one number is easier to apply than a set of numbers in one-third octave bands. However, some building materials and components are more effective at reducing low-frequency noise than other materials or components. Since aircraft noise contains a lot of low-frequency sound, it is important to ensure that insulating materials and components perform well at low frequencies. NLR is a good indicator of overall wall performance but may not be appropriate when designing modifications for aircraft noise reduction, especially if a good NLR value disguises poor low-frequency insulation.

2.4 Sound Insulation Objectives

The goal for residential sound insulation is to reduce the dwelling interior noise levels due to aircraft operations. Total "soundproofing" of the dwelling, such that aircraft operations are inaudible, is economically infeasible. Modest improvements over the existing characteristics (i.e., less than 5 dB) may not provide a noticeable improvement for the homeowner and hence are not cost effective. The ideal solution is to provide sound insulation which lies between these two extremes.

FAA Regulations and the Department of Defense Air Installation Compatible Use Zone (AICUZ) Studies address the issue of aircraft noise infringement on communities surrounding airfields. Both identify the normally acceptable levels of exposure outside dwellings for residential use. Tables 1-1 and 1-2 show the land-use compatibility definitions of the AICUZ program and the FAA, respectively.

Interior Noise Objectives

The DNL is the best predictor of overall long-term community reaction to noise from aircraft as well as other activities. Exterior noise exposure less than DNL 65 dB is normally considered compatible with residential land use. Noise exposure is normally incompatible above 65 dB unless stated noise reductions are achieved within the dwellings. A 25 dB NLR is required in the noise zone from 65 to 70 dB. From 70 to 75 dB, a 30 dB NLR is required. Above 75 dB, residential land use is generally deemed incompatible and should be discouraged by local officials.

Sometimes, the DNL noise reduction goal in habitable rooms is supplemented by a single-event noise level criteria. This Sound Exposure Level (SEL) reflects the annoyance associated with individual flyovers because of activity interference. The SEL goal is 65 dB in general living spaces and 60 dB in bedrooms and television viewing rooms. These criteria are only applied to homes within the DNL-defined noise impact area, not to homes outside the 65 dB DNL contour boundary.

To use the SEL interior noise criteria, the outside noise exposure level is compared to the interior goal. For example, if the dwelling is between the SEL contour boundaries of 85 to 90 dB, then the required NLR to achieve 60 dB in a bedroom would be 30 dB. (The conservative upper bound of the noise zone is normally used to set NLR goals.)

Room Variations

The noise level of different rooms in a house depends on the absorption within the room, as well as on the noise entering from outside. Upholstered furniture, drapes, and carpeting absorb sound while hard surfaces do not. In addition, different categories of room vary on how predictable their sound environments are. Living rooms, for example, tend to be consistent from one house to another because they almost always have the same types of furnishings in them. Bedrooms vary because some are guest rooms with less furniture, and some have been converted to other uses. Kitchens tend to vary widely due to the use of different wall coverings, such as cabinets and appliances, or floor coverings, such as tile or carpet. These room variations act in addition to variation in exterior sound level and sound transmission through the outside wall.

Geographical Differences

Climate influences housing construction in ways that affect the sound insulation. In warm climates, construction may be lighter weight, especially in the roof, windows, and doors. Conversely, in cold climates, especially where snow is likely, the roof tends to be thicker and heavier, as do the windows and doors. A heavier roof, especially if there is an attic present, improves the noise insulation of a home. While thermal windows are not as effective at reducing noise as they are at reducing heat loss, they offer minimal additional protection. Solid-core doors reduce noise better than hollow-core doors. Perhaps most significantly, good weatherstripping and sealing eliminate noise entering the home through air infiltration paths. Good sealing practices are more common in colder areas of the country.

Availability and local cost of materials exert an influence on construction decisions also. These variations all affect the noise reduction performance of homes.

Existing Conditions and Expected Improvements

An acoustically well-insulated home that is kept closed can provide 30 dB of noise attenuation. A more typical, unmodified dwelling might provide 20 to 25 dB of noise reduction. Experience has proved the objectives discussed here to be reasonable and effective for typical dwelling construction. In addition, the FAA has recognized that in order for a homeowner to perceive any improvement in the home's sound environment, there must be a minimum of 5 dB improvement in noise reduction in each room. It is not usually practical to try to provide more than 40 dB of NLR in a dwelling. Of course, no amount of noise reduction will have any effect on outdoor activities. The advantage of sound insulation is that it provides a refuge from high external aircraft noise levels.

2.5 Sound Insulation Concepts

Sound Transmission

In order to effectively examine noise control measures for dwellings it is helpful to understand how sound travels from the exterior to the interior of the house. This happens in one of two basic ways: through the solid structural elements and directly through the air. Figure 2-3 illustrates the sound transmission through a wall constructed with a brick exterior, stud framing, interior finish wall, and absorbent material in the cavity.

The sound transmission starts with noise impinging on the wall exterior. Some of this sound energy will be reflected away and some will make the wall vibrate. The vibrating wall radiates sound into the airspace, which in turn sets the interior finish surface vibrating, with some energy lost in the airspace. This surface then radiates sound into the dwelling interior. As the figure shows, vibrational energy also bypasses the air cavity by traveling through the studs and edge connections.

Openings in the dwelling which provide air infiltration paths – through windows, vents, and leaks – allow sound to travel directly to the interior. This is a very common, and often overlooked, source of noise intrusion.

Flanking is a similar concept and usually refers to sound passing around a wall. Examples of common flanking paths include: air ducts, open ceiling or attic plenums, continuous side walls and floors, and joist and crawlspaces.

The three different major paths for noise transmission into a dwelling – air infiltration through gaps and cracks, secondary elements such as windows and doors, and primary building elements such as walls and the roof – are displayed in Figure 2-4.

Low-frequency sound is most efficiently transmitted through solid structural elements such as walls, roof, doors, and windows. High frequencies travel best through the air gaps. Within these broad categories, different building materials have different frequency responses to sound and varying abilities to insulate against sound.

Reducing Transmitted Sound

The amount of sound energy transmitted through a wall, roof, or floor can be limited in several ways. First, all air infiltration gaps, openings, and possible flanking paths must be eliminated wherever possible. This is the single most important, but occasionally overlooked, step in noise reduction. This includes keeping windows and doors closed and putting baffles on open air vents.

Some materials reflect more of the incident sound, converting less of it into vibrational energy. The mass of the exterior and interior panels influences how much sound will pass through them. The more mass a structural element has the more energy it takes to set it into vibration, so adding weight to a wall or ceiling by attaching a gypsumboard layer will make the assembly pass less sound. Then, absorption in the air cavity and resilient mounting of interior finish panels can further reduce the sound transmitted to the room.

The primary approaches for improving sound isolation are:

1. Elimination of openings and flanking paths (when accessible).
2. Improvement of windows and doors.
3. Massive construction (build a wall 3 feet thick and 40 feet high around the whole house);
4. Isolation of panel elements through separation or resilient mounting;
5. Absorption.

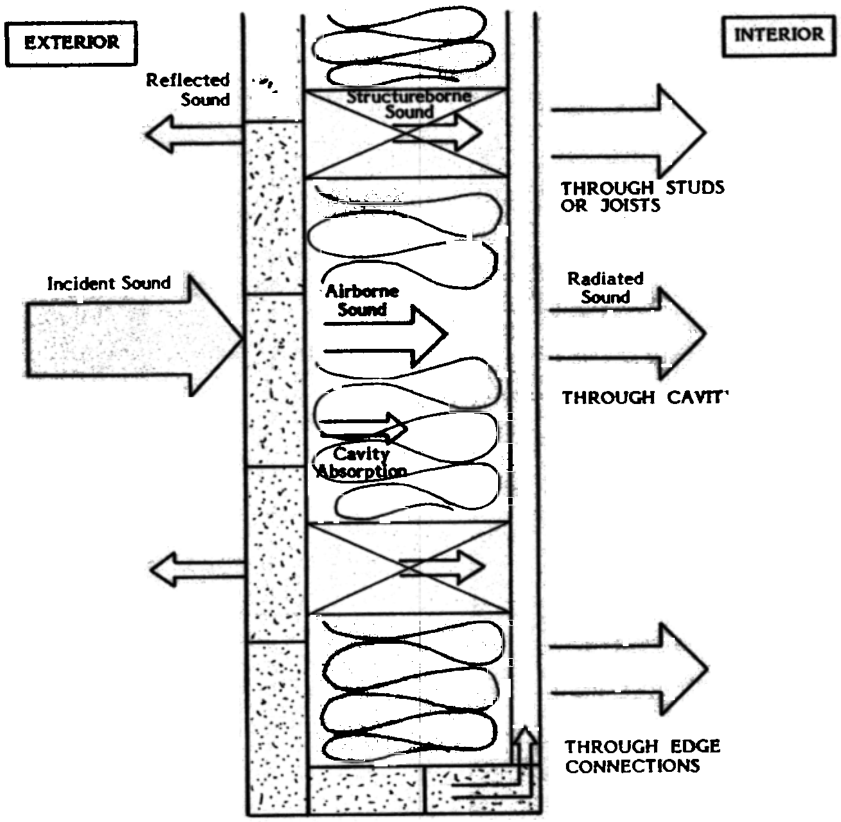

Figure 2-3. Pictorial Representation of Sound Transmission Through Built Construction.

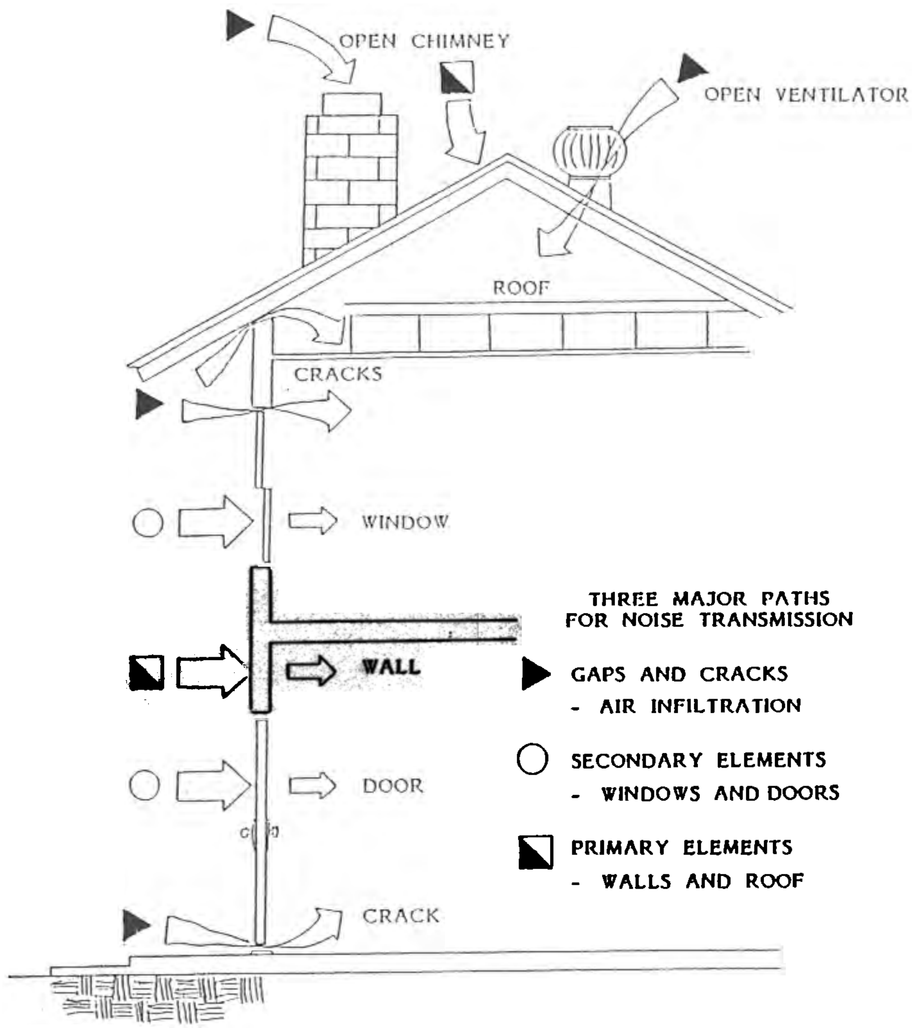

Figure 2-4. Sound Transmission Paths Into Dwelling Interiors.

Balanced Acoustical Design

The most important, or controlling, sound paths must be identified in order to know how to modify a dwelling to meet a specified noise criteria. The ideal sound insulation design would achieve a condition where all the important sound paths transmit the same amount of acoustical energy. This eliminates any weak links in the building's insulation envelope and is commonly referred to as a *balanced acoustical design.*

As an example of the importance of a balanced acoustical design, Figure 2-5 illustrates the effect of introducing windows with poor sound insulation properties to a siding wall. The sound level in decibels (dB) is noted at the outside and the inside and the transmission loss (TL), or drop in sound power, is given in the right-hand column (see Section 2.3 for further discussion of TL). As more of the wall area is taken up with windows, the overall noise protection decreases.

This effect is significant even for massive wall materials, such as the brick wall shown in Figure 2–6. Intuition suggests that this wall would protect better against sound than the siding. In this example, however, the brick construction performs poorly because of the use of low sound insulation windows (STC 25) compared to a siding wall with acoustic windows (STC 30). The STC rating, defined in Section 2.3, is a measure of the material's ability to insulate against sound; the higher the STC rating, the better the insulator. Proper use of STC ratings will be discussed in more detail in Section 3.5.1.

In most cases, after leaks and gaps are sealed, the windows are the controlling sound path. Replacing them with acoustical windows typically does more to improve the sound insulation performance than any other architectural modifications. Once this is done the other elements may become important in meeting specific noise reduction goals. Exterior doors often require improved sound insulation. Ceilings and walls which face the exterior may require modification as well, particularly in the higher DNL noise zones. Treatments for these paths and others are discussed in Section 3.5.2 of this handbook.

Problem Areas

Sound intrusion problems are commonly caused by:

1. Building construction components and configurations not providing sufficient sound insulation.

2. Structural elements, such as windows, doors, walls, roofs, and floors chosen and combined in an unbalanced way so that some parts are much weaker sound insulators than others.

3. Unintended openings or sound-flanking paths caused by deterioration or improper installation of construction elements.

New Construction Versus Old

Dwellings can vary in their sound isolation performance. Generally, air infiltration, and therefore sound infiltration, around windows and doors tends to be worse for older dwellings. This is usually caused by inadequate or deteriorated weatherstripping and misaligned framing. On the other hand, most older construction techniques and materials tend to be more massive than newer lighter-weight construction. As a result, many older buildings tend to perform better with regard to sound transmission through walls, roofs, and floors than do new houses. Homeowner modifications can also degrade the dwelling's sound insulation performance. Examples include home improvements such as skylights, whole-house attic fans, through-the-wall air conditioners, and solariums.

In general, it is much more efficient, and cost effective, to take acoustic performance into account when designing and building a home at the start. Remodeling an already built home is more costly and time consuming than anticipating and building for good sound insulation. Most of the insulation methods discussed in Section 3.5 can be used directly in new construction. Section 3.5.3 gives some specific suggestions.

Thermal Insulation

While homes which are well insulated thermally often perform well acoustically, thermal insulation is not always a good indicator of sound insulation. Many thermal windows, installed in new construction or added as a homeowner upgrade, provide little sound insulation when compared to walls or acoustical windows and are frequently the weak link in the building envelope. However, thermal treatments usually eliminate air infiltration and may serve to improve the acoustical

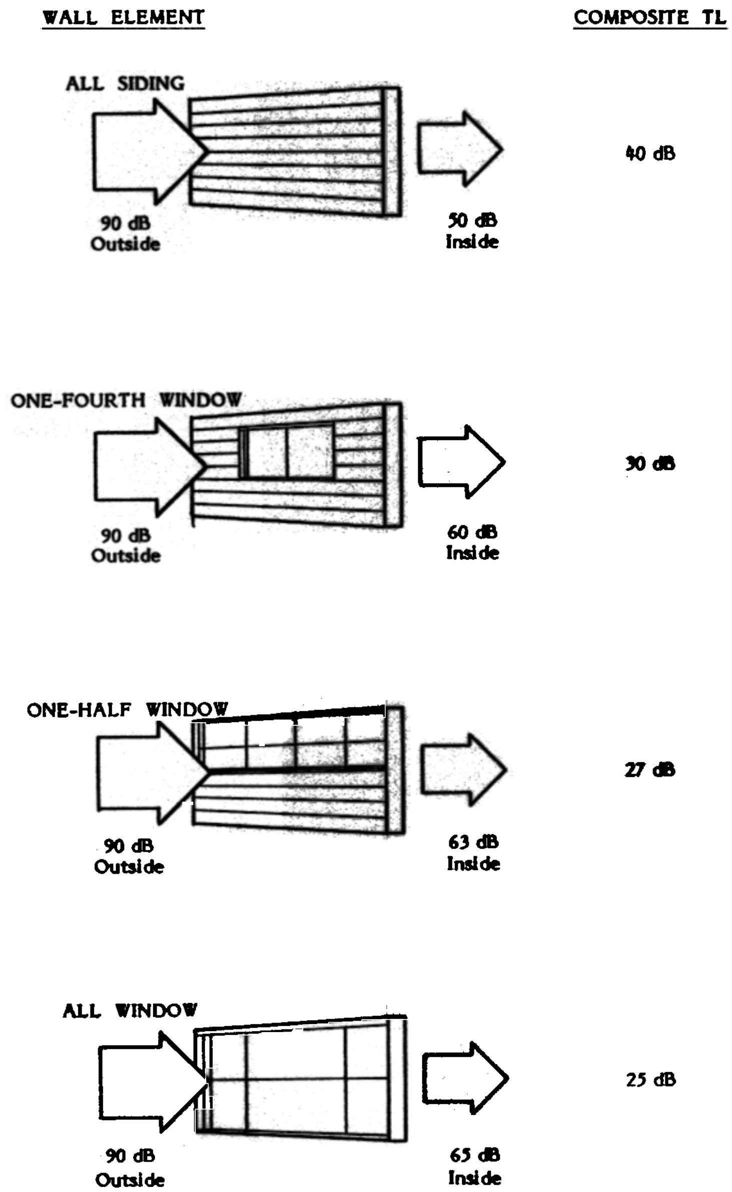

Figure 2-5. Effects of Window in Lowering the Composite TL in Complex Constructions.

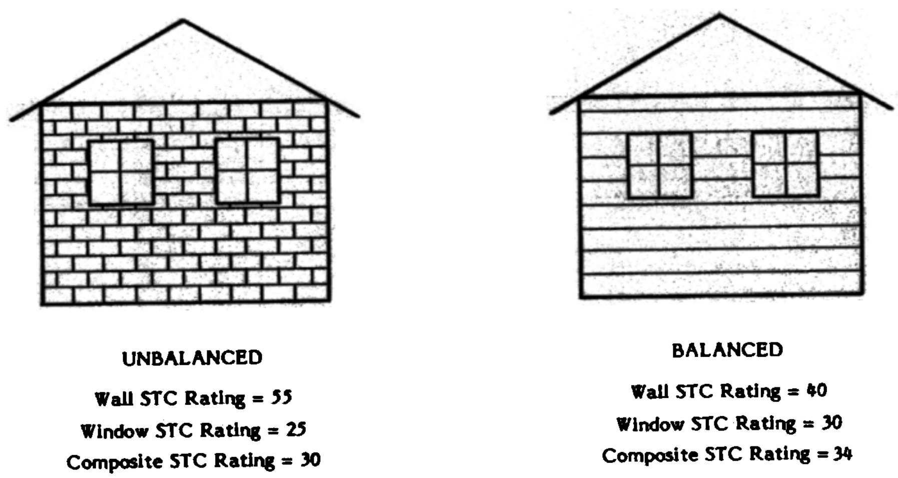

Figure 2-6. Conceptual Illustration of Unbalanced and Balanced Constructions.

performance of a dwelling. And, as Section 3.5.2 discusses, thermal insulation batts are often useful in the wall cavities and attic spaces to absorb some sound.

Shielding

The last concept to consider is shielding. This refers to the fact that the side of the dwelling which faces away from the flight path and does not have an open line-of-sight to it will be protected somewhat from the noise. Figure 2–7 displays this concept. Other sides of the house, facing directly toward the flight path, are unshielded. Sides which face the flight track at an angle may benefit from some shielding effects. Sometimes, however, sound is reflected off nearby buildings in such a way as to counteract the shielding benefits. The shielding may be as much as 10 dB[5] in some cases, though values on the order of 5 dB are more common. Shielding must be examined on a case-by-case basis and the possibility of aircraft straying from the flight path must be taken into account before assuming a consistent shielding effect.

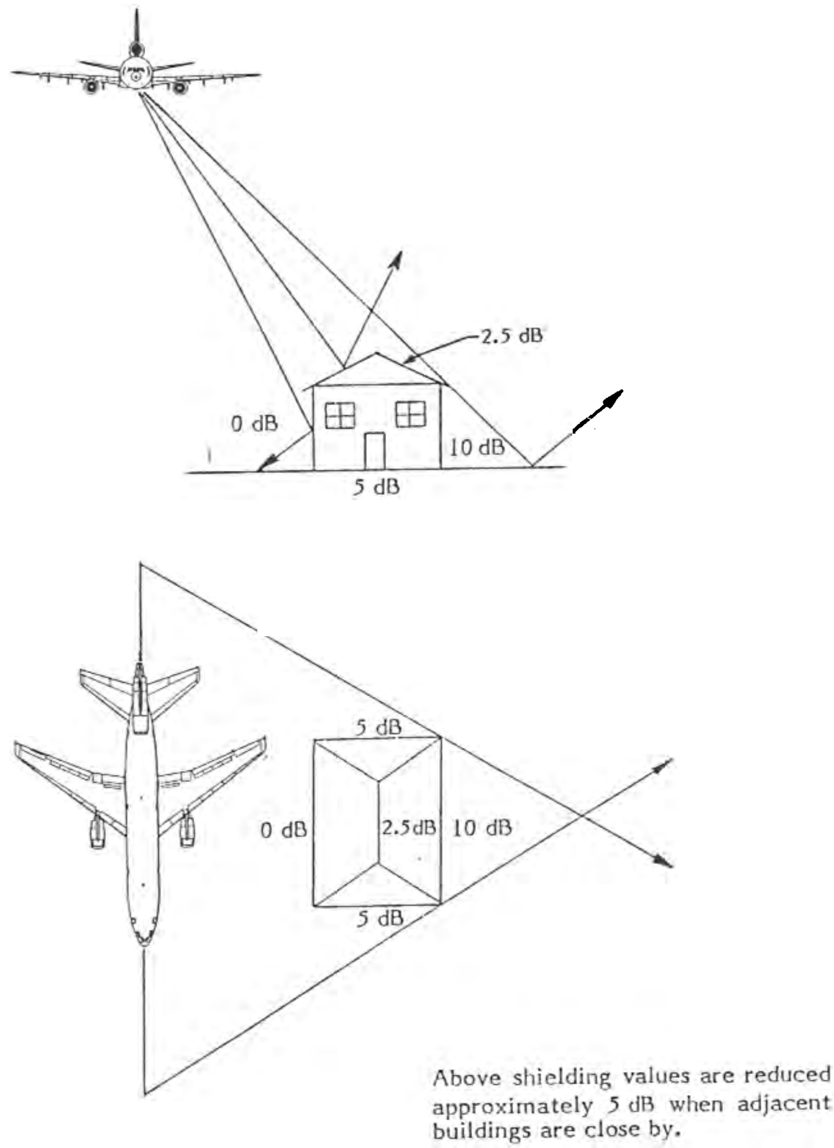

Figure 2-7. Measured Values for Acoustical Shielding Due to Aircraft Noise.