CHAPTER 6

Measuring Airport Noise

Overview

By one common definition, noise is simply *unwanted* sound. *Sound* is something which can be precisely defined and physically measured. *Noise*, on the other hand, is highly subjective. Sounds which may be pleasant and desirable to one person may be noise to someone else. Moreover, even when people agree that a sound constitutes noise, their reactions to that noise may vary substantially.

The subjective and highly complex nature of noise is implicit even in the measurement of noise. These characteristics are particularly evident with respect to measurement of airport noise. As discussed in this chapter, airport noise differs in many respects from other sources of noise, including other transportation noise. Also discussed are the efforts which have been and continue to be made to devise ways of describing and quantifying airport noise. Lastly, issues involved with measuring noise levels for a particular airport and projecting potential future noise impacts are addressed.

This chapter examines the various factors involved in measurement of airport noise. The discussion covers:

- Characteristics of airport noise
- Airport noise metrics
- Calculation of airport noise contours

The chapter which follows addresses the issue of setting land use compatibility policies on the basis of airport noise data.

Characteristics of Airport Noise

Noise is often perceived to be the most significant of the adverse impacts associated with airport activity. To better understand airport noise impacts, it is important to recognize the variables involved with regard to different types of aircraft, aircraft flight routes, and other factors such as pilot technique.

As background to the topics which follow, an understanding of the fundamental characteristics of sound is valuable. Tables 6A and 6B provide some basic information on sound measurement and sound attenuation, respectively. Figure 6A lists typical sound levels of common indoor and outdoor sound sources.

Types of Aircraft

As experienced on the ground, the noise emitted by different types of aircraft has distinct differences in terms of both the overall sound level and other properties. The extent of the differences in sound levels generated by a selection of general aviation, air carrier, and military aircraft can be seen in Figure 6B. The illustrations depict the typical noise "footprint" created by

Sound

Sound is transmitted in the form of pressure waves. These waves are created by oscillation of particles of air—that is, air particles being displaced from and returning to an equilibrium position. As the particles are displaced, they bump into surrounding particles which bump into others and so on. In this manner, sound is transmitted through the atmosphere. Sounds are heard when the pressure waves of displaced air particles strike the eardrum, causing it to vibrate.

The physical properties of a sound can be measured in terms of three basic components: *magnitude, frequency,* and *duration*. Although these components can be directly measured, useful measures of sound are complicated both by environmental variables and the way in which people hear sound.

Magnitude

The magnitude or strength of a sound is determined by how much the air particles are displaced from equilibrium by the sound pressure waves. The greater the amplitude of the pressure fluctuation, the more acoustic energy the sound wave carries. Simply measuring the magnitude of sound on a linear scale is not practical, however, because the range of sound pressures which the human ear can detect is enormous—a ratio of 1 to approximately 10^{14} (1 followed by 14 zeros). By converting this ratio to a logarithmic scale, the range can be reduced to 14 units. The unit of sound level measurement on this scale is the bel (in honor of Alexander Graham Bell). Normally, though, these units are divided into tenths—that is, *decibels*. The range of human hearing thus extends from 0 decibels, corresponding to the faintest sound level that the healthy, unimpaired human ear can detect, to more than 140 decibels. (Sound levels of nearly 200 decibels are possible—such as inside a rocket engine—but are greater than the unprotected human ear can withstand.)

The use of a logarithmic scale for measurement of the magnitude of sound is often the cause for confusion because it does not directly correspond to the way in which people perceive the relative *loudness* of different sound levels. People tend to think that, if two equal sounds are combined, the result will seem twice as loud. In reality, however, combining two equal sounds—although it doubles the sound energy—produces only a 3 dB increase in magnitude, an amount which is bare perceptible. For one sound to be judged twice as loud as another, it actually must be 10 dB higher (meaning that the acoustic energy must increase 10-fold). Because we perceive the loudness of sounds in relative rather than absolute terms, the relationship of 10 dB per doubling of loudness applies to any 10 dB increase—sound level increases from 40 dB to 50 dB or from 80 dB to 90 dB are both perceived as representing a doubling of loudness.

Frequency

The frequency of a sound—its *tonal quality*—depends upon the relative rapidity of the air pressure oscillation. In a low-pitched tone, the sound waves are relatively far apart (that is, the wavelength is relatively long), while in a high-pitched tone they are squeezed much closer together. Frequency is measured in cycles per second (also called *hertz* or Hz). Although some *pure* tone sounds contain only one frequency, more often sound is a mixture of different frequencies.

The response of the human ear to different sounds is significantly affected by the frequency of those sounds. Although people can hear sound frequencies as low as 20 Hz and as high as 20,000 Hz, they do not hear all frequencies in this range equally well. Very low and very high frequency sounds are perceived to be less loud than mid-range sounds.

Most environmental sound measurements consequently are weighted to simulate the varying frequency sensitivity of the human ear. A widely used weighting for general environmental sounds (as opposed to large-amplitude impulse sounds such as sonic booms) is the A-weighted sound level expressed in decibels (abbreviated as "dBA").

Duration

The third component of sound is the length of time over which it occurs. Many sounds have a distinct beginning and ending; others, such as from aircraft overflights, gradually increase and decrease without a sharp definition of when they start or stop. In the latter case, the duration of the sound is usually measured in terms of the time period over which the sound level exceeds a specified threshold.

Because sound levels vary from one moment to the next, it is not possible to say that a given noise was "so many decibels" except when referring to an instantaneous measurement or by averaging the sound level over time. As discussed elsewhere in this chapter, numerous methods have been developed which seek to measure the overall *exposure* produced by a noise event or events within a defined period of time.

TABLE 6A

Measurement of Sound

Sound Attenuation in the Outdoor Environment

Among the basic characteristics of sound which are of particular interest in the discussion of aircraft-generated noise are sound attenuation or reduction over distance. Part of the reduction occurs because sound energy is spread over a three-dimensional, geometrically increasing area as the distance from the source increases. At sufficient distances from the source, geometric spreading alone results in a 6 dB loss per doubling of distance. Actual attenuation of sound is greater than this as a result of factors such as absorption by the atmosphere. Also, atmospheric attenuation is greater for high-frequency sound than for sound with a low frequency.

Other factors also influence the extent to which sound is attenuated in the environment. Sound propagation through the air is affected by meteorological conditions including air temperature, temperature inversions, humidity, wind speed, and air turbulence. Sound traveling along a hard ground surface is attenuated by approximately an additional 2.5 dB in 1,000 feet (compared to the attenuation in air alone) and tall grasses or shrubs can double this figure. Structures, terrain, or other barriers can provide significant attenuation for ground-to-ground sound as well.

Ground cover and objects on the ground, however, have little effect on reducing air-to-ground sound such as that from aircraft. Moreover, buildings and other such objects can cause reflections which may even *increase* the localized sound level.

Sound Attenuation Provided by Buildings

For indoor activities, another significant factor affecting the level of aircraft-generated noise to which people are exposed is the amount of sound attenuation provided by the building. The sound insulation capabilities of buildings are measured in several ways.

One measure commonly associated with the individual structural components of a building is the *Sound Transmission Class* (STC). The STC rating of a component is expressed as a single number, in decibels, and is calculated in laboratory testing of the component. STC ratings are often used in construction specifications to indicate a required sound insulation capability. The original application of STC ratings was with regard to interior partitions, but it can also give some indication of the sound attenuation provided by exterior walls, windows, and doors.

Caution must be used, however, when attempting to evaluate the exterior-to-interior sound level attenuation of a building by means of STC ratings. First, as a single number, the STC of a structural component may not adequately reflect differences in the component's relative abilities to block sounds of different frequencies. Secondly, the overall sound attenuation provided by most buildings cannot be calculated from STC ratings. The various components of a building each have different noise insulation qualities. Moreover, sound tends to enter an interior space not so much through individual components, but by way of openings and gaps such as vents, door jambs, and so forth. Interior noise levels from exterior sources thus are substantially determined by the weak link in the overall construction.

A more general measure of a building's sound attenuation attributes is its *Noise Level Reduction* (NLR). Like STC, NLR is a single-number value measured in decibels and as such may disguise a building's varying response to different sound frequencies. Unlike STC, though, NLR is measured in field testing of actual structures. It thus takes into account the fact that buildings are made up of numerous components.

(See Chapter 7 for a discussion of interior noise level standards and sound insulation programs.)

TABLE 6B

Sound Attenuation

In several respects, aircraft noise is intrinsically different from other types of transportation noise.

- *Directionality:* Few other noises routinely come from overhead.
- *Intermittent Occurrence:* Unlike the often constant drone common from highway noise, aircraft noise is usually composed of discrete events.
- *Vibration:* Blade slap noise from helicopters and the low- frequency rumble created behind jet aircraft as they take off often cause perceptible vibration in structures.
- *Fear:* In part because the source is from overhead, there is sometimes a sense of fear attached to how people perceive aircraft noise that is seldom evident with noise from highways and railroads.

As discussed later in this chapter and in the chapter which follows, these characteristics often necessitate different approaches to airport noise impact mitigation than are used with respect to other noise sources.

a single landing and takeoff of each aircraft. Each of the footprints is broadly representative of those produced by other aircraft similar to the ones included. However, the actual sound level produced by any single aircraft takeoff or landing will vary not only among specific makes and models of aircraft, but also from one operation to another of identical aircraft.

Jet Airplanes

Both the character and the sound level (magnitude) of jet airplane noise has changed over time as new engine technologies have been developed and introduced into the airline and business jet aircraft fleets. The old, pure-jet engines produce noise that is both very loud and at the high end of the frequency spectrum. Newer generation, fan-jet engines—in which a substantial volume of the air entering the engine bypasses the combustion chamber—create noise that is comparatively lower both in magnitude and frequency. Even among fan-jet engines, noise levels have been considerably reduced with the most recent models compared to the earliest types.

Most of the overall noise level improvements experienced in recent years at airports having jet activity have resulted from retirement of the older, louder jet aircraft. As of January 1, 2000, the older-model, so-called Stage 2, fan-jet aircraft have been phased out of the nation's airline fleet in accordance with federal law. In many cases, though, compliance with the current Stage 3 phase-out standards has been accomplished not by retirement of the entire aircraft, but by replacement or modification of the engines. Although aircraft retrofitted with "hush kits" meet the present standards, they remain comparatively more noisy than newer-technology aircraft. Additionally, the Stage 3 standards apply only to aircraft weighing more than 75,000 pounds. The many Stage 2 business jet aircraft which weigh less than this amount are still allowed to operate. Such aircraft can produce a significant proportion of the noise impacts at general aviation airports.

Furthermore, the effect of the technological improvements on aircraft noise levels differs between takeoffs (departures) and landings (approaches). Decreased engine exhaust noise together with improved climb-out performance (aircraft reach a higher altitude more quickly) have enabled major reductions in departure noise levels. Approach noise has also recently become a more prominent issue. Greater noise emissions from the fans and compressors in high-bypass engines have increased the comparative importance—and sometimes the actual noise levels—of aircraft approaches. One further concern to be addressed is sideline noise produced by the reverse thrust applied as aircraft land. This noise, particularly evident lateral to runways, can be the subject of complaints, but usually has little effect on overall noise contours because of the dominance of takeoff noise.

With regard to aircraft noise emissions standards, see the discussion of federal laws and regulations in Chapter 7.

The extent to which jet aircraft noise will be further reduced in the future depends upon several factors. Continued technological advancements appear capable of reducing noise emissions to levels below those of the newest aircraft now in production. The question then becomes one of how quickly such technologies will be introduced into the national and world-

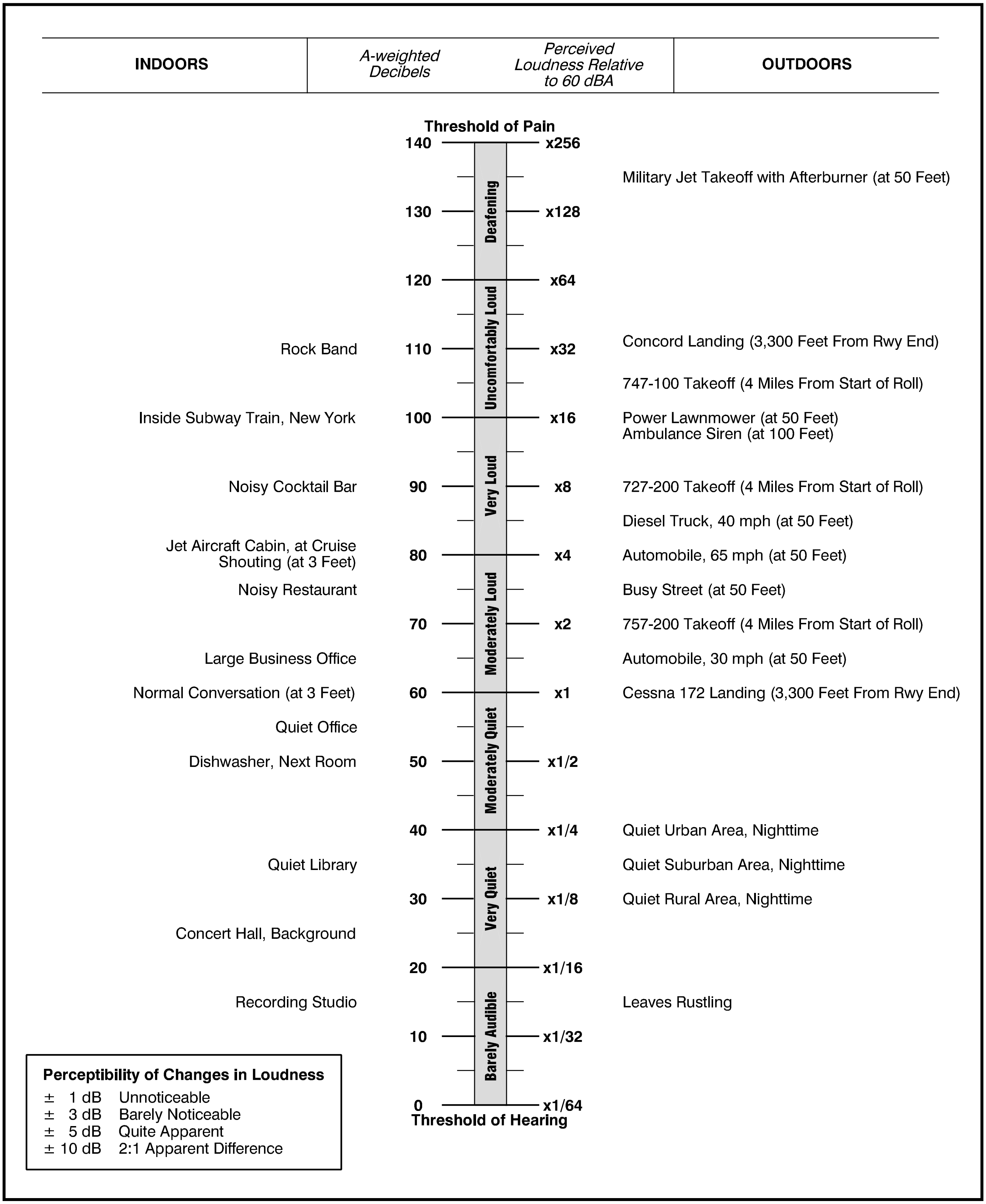
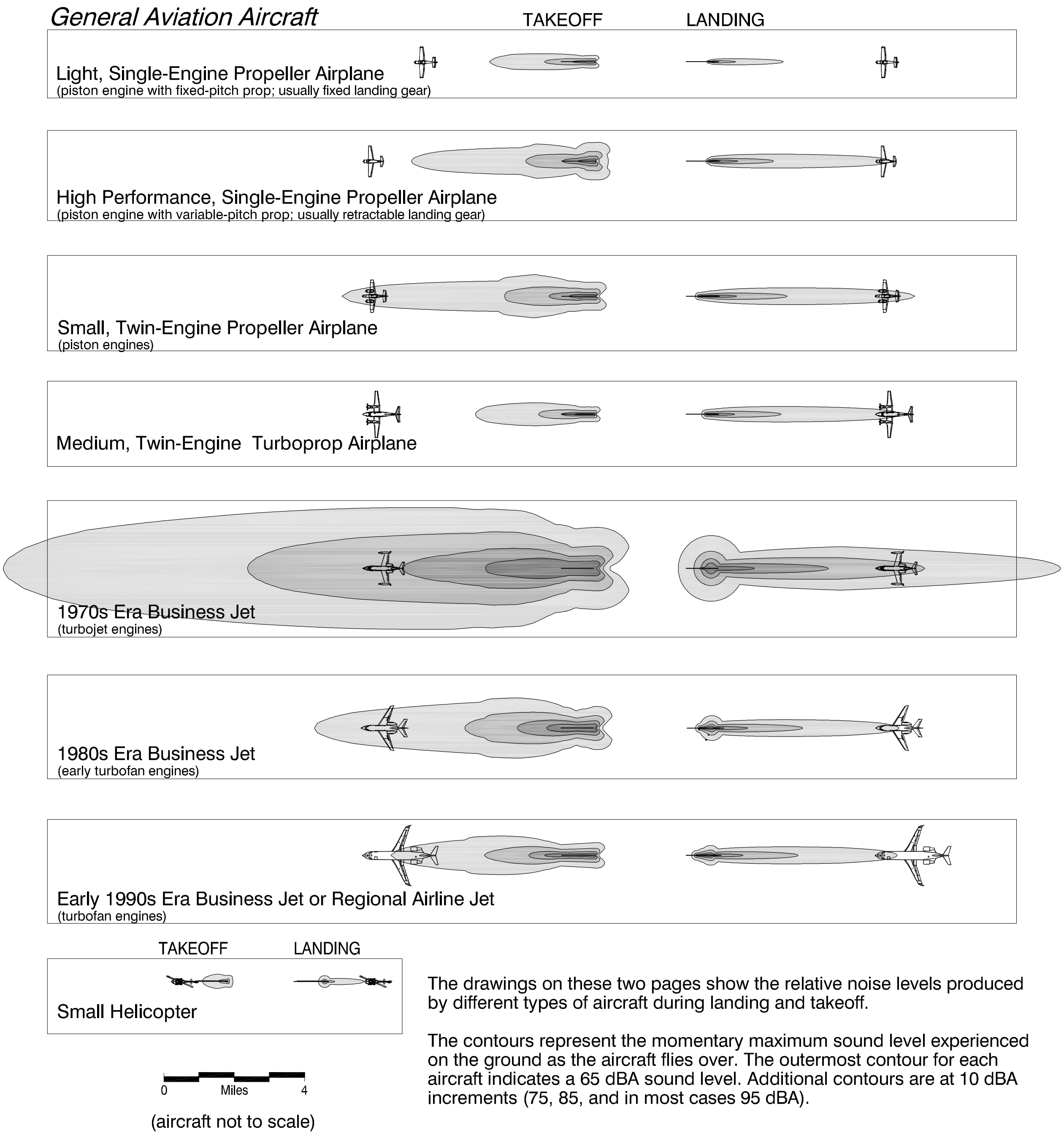


FIGURE 6A

Typical Decibel Level of Common Sounds



The drawings on these two pages show the relative noise levels produced by different types of aircraft during landing and takeoff.

The contours represent the momentary maximum sound level experienced on the ground as the aircraft flies over. The outermost contour for each aircraft indicates a 65 dBA sound level. Additional contours are at 10 dBA increments (75, 85, and in most cases 95 dBA).

FIGURE 6B

Noise Footprints of Selected Aircraft

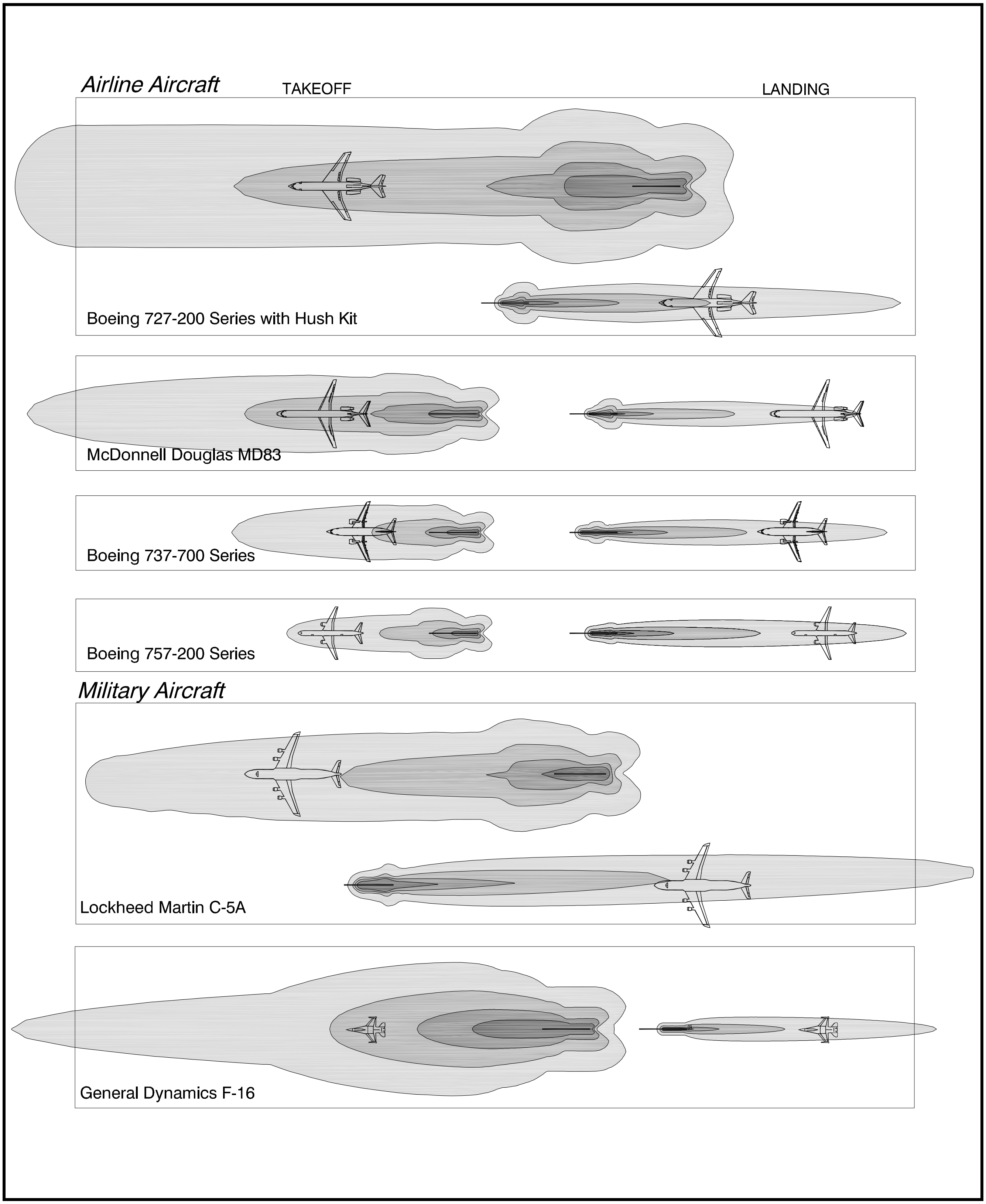


FIGURE 6B *CONTINUED*

wide aircraft fleets. Also an important consideration is the rate at which older, noisier aircraft will be phased out of operation. Lastly, in terms of cumulative noise impacts, a key factor is the volume of future aircraft operations. Even with improved technologies, the potential exists for the overall noise level at airports to increase along with growth in the number of aircraft operations.

Propeller Airplanes

The dominant noise from most propeller airplanes, whether they are driven by piston or turbine engines, is from the propeller itself. Propeller airplane noise varies depending upon the number of engines, the rotational speed of the propellers, the number of blades on each propeller, and the pitch of the blades, as well as, to some extent, the type of engine.

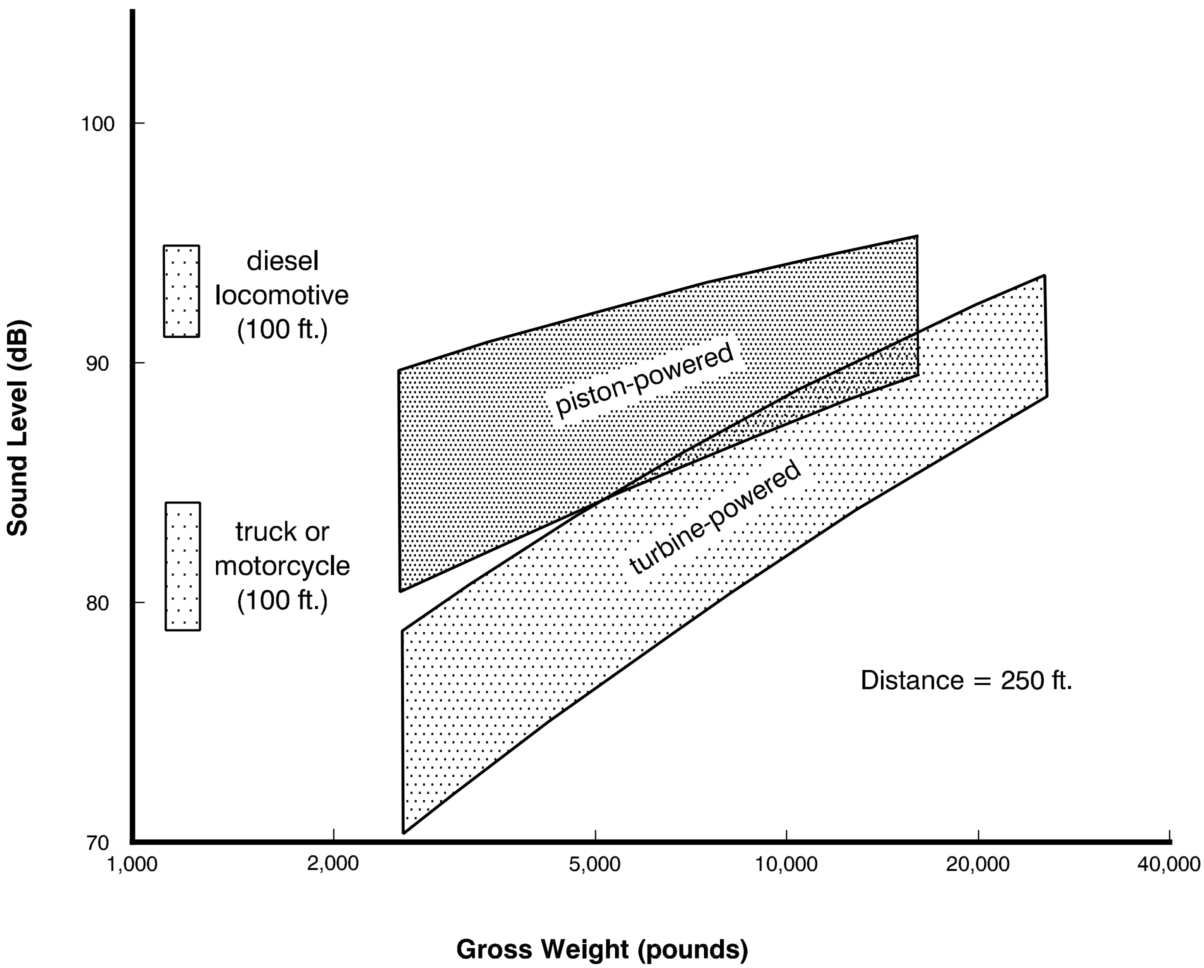
A common perception is that propeller airplanes typically emit significantly less noise than jet airplanes. Early-technology (and most tactical military) jet aircraft clearly are very noisy—more so than most propeller airplanes. With current model jets, however, the distinction is much less. Indeed, aircraft weight accounts for much of the difference. Most propeller airplanes flying today are substantially smaller and lighter than jet airplanes. For aircraft of similar weight, the noise levels of aircraft that are propeller driven and those that have new-technology, fan-jet engines are not greatly different. Another factor affecting the relative noise levels generated by the two aircraft types is the takeoff climb profile. Because jets climb much more rapidly than typical propeller airplanes, the noise levels measured on the ground diminish rapidly with increased distance from the runway. Consequently, at points sufficiently far from the runway end, the higher altitude attained by jets may make them effectively quieter than propeller airplanes. This phenomenon can be seen from comparisons among the aircraft noise footprints depicted in Figure 6B.

Unlike jet aircraft, the noise levels produced by average, propeller-driven, small airplanes found at general aviation airports has not changed appreciably over the years. The potential for future technological improvements is limited. Moreover, small, private airplanes tend not to be replaced with newer models at anywhere near the rate common to airline aircraft. Thus, for many years to come, the noise impacts of typical propeller airplanes are likely to remain little different from what they are now.

Helicopters

Figure 6C depicts the normal sound level range of helicopter operations, measured at a distance of 250 feet.

Helicopter noise has a character all its own. Although a portion of the noise emanates from the engines themselves, the uniqueness of helicopter noise is mostly due to the modulation of sound created by the relatively slow-turning main rotor. This sound modulation is referred to as *blade slap*. Blade slap is most pronounced during low-speed descents and high- speed cruise. To a listener on the ground, it is most audible as the aircraft approaches. Helicopters are also notable for creating vibration or rattle in structures.



Source: Helicopter Association International (1993)

FIGURE 6C

Helicopter Noise Levels

Research into methods of reducing helicopter noise is on-going. Remaining to be seen is how successful and cost-effective the results will be.

Common Aircraft Flight Routes

The discussion in this section concerns the flight routes and procedures used by aircraft under normal flying conditions. Chapter 8 contains information regarding how pilots and aircraft react under emergency circumstances.

An essential point to emphasize in this discussion of aircraft flight routes is that airport land use commissions have no authority to regulate where aircraft fly. That responsibility rests with the FAA and, to a lesser degree, with airport proprietors.

In general, the most significant noise impacts created by aircraft are concentrated near the ends of airport runways. The locations of aircraft flight routes to, from, and around an airport, however, are also a major determinant of where noise impacts occur. This section describes the major factors which determine the type and location of aircraft flight routes near airports.

Types of Flight Rules

Aircraft fly to and from airports under two different sets of operating procedures defined by Federal Aviation Regulations:

➤ **Visual Flight Rules (VFR)**—VFR operating procedures apply at airports when weather conditions (specifically, the horizontal visibility and the cloud ceiling height) permit pilots sufficient time to see a runway for landing as well as to see and avoid other aircraft in flight and obstacles on the ground. These minimums are set by Federal Aviation Regulations Part 91. Within controlled airspace around airports the minimum visibility requirement for VFR flight is basically 3 statute miles. By requesting a special VFR clearance, pilots can obtain minimums as low as 1 statute mile. Minimums of 1 statute mile also are permitted in uncontrolled airspace.

➤ **Instrument Flight Rules (IFR)**—Under IFR procedures, pilots must rely on the aircraft's cockpit instrumentation, ground- or satellite-based navigational aids, and (where available) air traffic control services. IFR procedures are required when the weather conditions are below the minimums for VFR operations.

  Airport instrument procedures fall into two basic categories: *approach procedures* and *departure procedures*. Published procedures for individual airports are formally defined in accordance with federal guidelines and must be approved by the FAA. Airports may have one or more of each type of procedure based upon different navigational aids and applicable to different runway ends.

A mixture of VFR and IFR procedures are frequently used for aircraft operations at airports. IFR procedures can be followed during VFR conditions. This is the standard practice for airline aircraft, is often used by corporate aircraft, and also occurs during instrument flight training. Additionally, VFR procedures are often used at the termination of an IFR flight once the pilot has the airport in sight.

Airplane VFR Traffic Patterns

Federal Aviation Administration guidelines establish the standard traffic pattern flown by airplanes approaching and departing airports under VFR conditions. Airplane traffic patterns are defined in terms of a generalized *routing* and an *altitude* (or height above the airport).

The generalized routing is in the form of a racetrack-shaped path leading to and from the runway in use (Figure 6D). FAA guidelines specify only the shape of the pattern, not its size. Unless precluded by local conditions, traffic patterns use left-hand turns. The direction of flow within a traffic pattern depends mostly upon wind conditions. When winds are moderate to strong, aircraft will almost always take off and land facing as closely into the wind as the choice of runway alignment permits. When winds are calm or mild, other factors such as attaining the most efficient flow of traffic or minimizing noise impacts may influence which runway direction is used.

It is important to realize that, although most pilots normally fly a standard pattern at a nontowered airport, use of such a pattern is not mandatory. Depending upon the direction from which the flight is coming, a pilot may choose to make a *base entry* or *straight in* approach to landing. Also, after takeoff, an aircraft may depart the pattern at various points.

Traffic patterns at airports where an airport traffic control tower is operating are more regulated, but often more variable, than at airports without towers. Pilots commonly request the type of entry or departure which will be most convenient to them. Controllers usually grant such requests if conditions allow. However, when traffic is heavy, controllers may tell pilots which aircraft to follow and when to make turns. Atypical flight tracks can sometimes result.

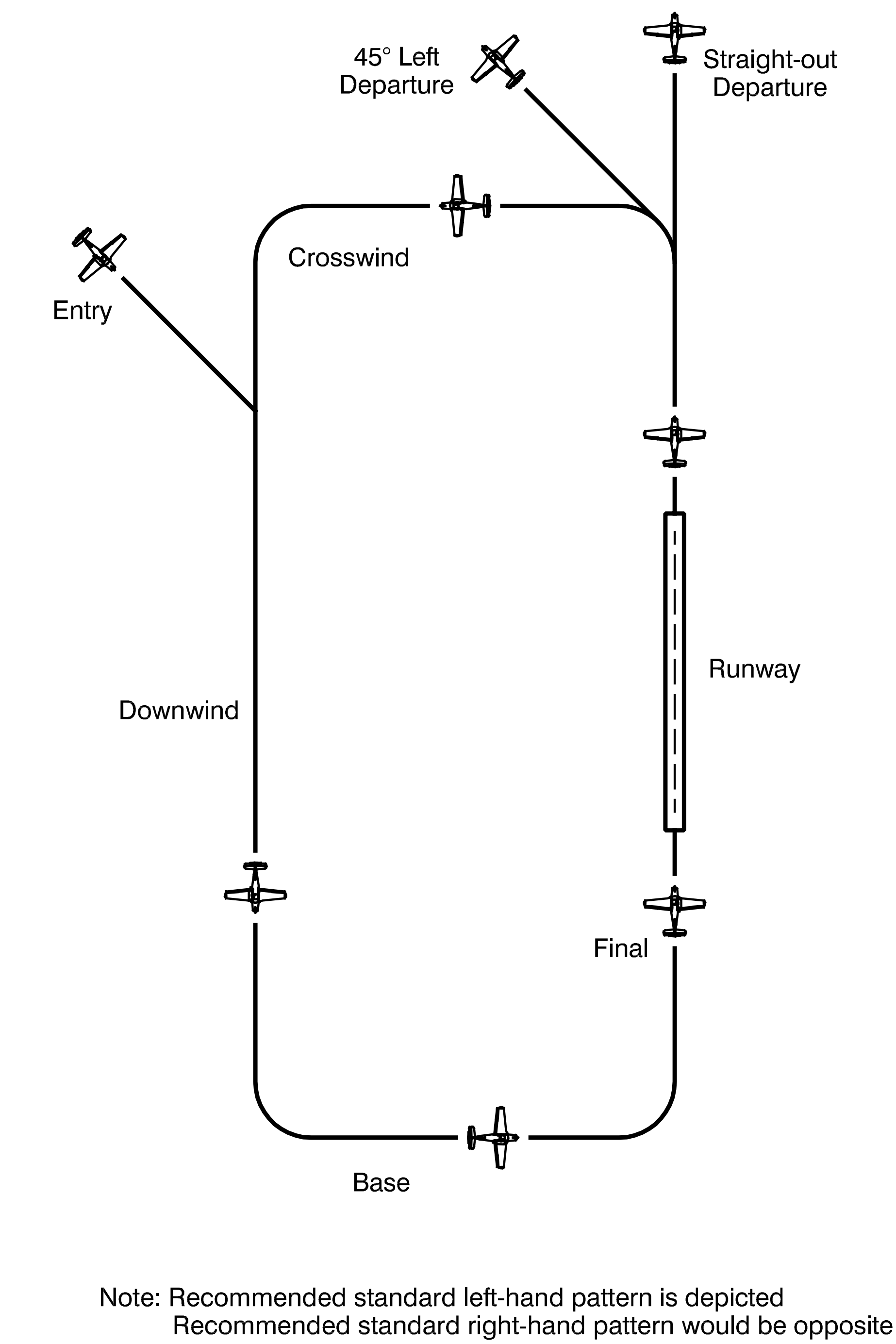
The existence of standard patterns tends to give people who are not pilots the impression that aircraft follow well-defined *highways in the sky*. The reality is that considerable variation occurs in how pilots fly traffic patterns. This variation is expected and normal.

- **Landings**—For landings, pilots of average single-engine airplanes usually fly the downwind leg (see Figure 6D) anywhere from ¼ to 1 nautical mile (1,500 to 6,000 feet) laterally from the runway. The base leg may extend even farther from the airport, particularly when other aircraft are in the traffic pattern. There is a tendency by many pilots to fly a relatively wide pattern at airports with a long, wide runway even when no other aircraft are present. Also, terrain and other local conditions can affect how traffic patterns are commonly flown at any given airport. When larger and faster airplanes fly a traffic pattern, the pattern is not only typically higher, but also farther out than one flown by smaller airplanes.
- **Takeoffs**—On takeoff, the normal procedure for small airplanes is to fly straight ahead until reaching an altitude of at least 400 feet above the airport. Depending upon runway length, aircraft type, air temperature, and pilot technique, this altitude may be reached over the end of the runway or not until nearly a mile beyond the runway end. Some pilots (especially those of agricultural aircraft) begin a turn at a lower altitude. Jets and other large airplanes normally climb straight ahead until reaching an altitude of at least 1,500 feet.

At most airports, the traffic pattern altitude for small airplanes is set at 800

Figure 6E depicts the actual flight tracks at an airport having both airline and general aviation operations, recorded from FAA radar over two six-hour periods. Although certain primary traffic corridors can be seen, the significant diversity in flight track locations is also apparent. Additionally, even for aircraft following nearly identical tracks, performance differences and the need to avoid conflicts with other aircraft results in wide variations in aircraft altitudes at any given point along a track.

These variations in flight paths and altitudes may be somewhat reduced in the future. At least near major airline airports, newly emerging technologies are expected to enable aircraft to closely follow precisely defined flight paths. The potential for creation of enhanced noise abatement flight procedures is yet to be explored.



Source: Aeronautical Information Manual (Section 4-3)

FIGURE 6D

Standard Traffic Pattern

Note: This map depicts a selection of actual flight tracks compiled from Sacramento International Airport radar data over a period of several hours. Arrivals are from the north and departures are to the south. Closed-circuit tracks mostly represent general aviation flight training activity.

N

0 Miles 5

Source: Sacramento County Airport System Noise Office

FIGURE 6E

Sample Plot of Actual Flight Tracks

to 1,000 feet above the airport elevation. Higher altitudes are sometimes established for large aircraft. These altitudes, however, apply only to a portion of the traffic pattern (mostly the *downwind* leg). Elsewhere in the pattern, aircraft are descending toward a landing or climbing after takeoff. FAA regulations regarding minimum en route altitudes (in populated areas, 1,000 feet above the highest obstacle within 2,000 feet of the aircraft) do not apply while an aircraft is landing at or taking off from an airport. The actual altitude of an aircraft at any particular point along the traffic pattern is largely dependent upon its performance capabilities plus, on landing, any visual glide slope guidance which may be installed at the airport.

Instrument Approach Procedures

Instrument approach procedures are classified as either *precision* or *nonprecision*.

The FAA has recently created a third category of instrument approach procedures: *approach procedure with vertical guidance (APV)*. These procedures are similar to precision approach procedures in that they provide vertical guidance. However, for any of several reasons, they do not fully conform to international standards for precision approach procedures.

- **Precision Approach Procedures**—Precision approach procedures provide both vertical and horizontal guidance to the aircraft. Current procedures all rely upon using navigational aids located at the airport and elsewhere on the ground nearby. In the future, the satellite-based Global Positioning System (GPS) is expected to enable precision approaches without the need for navigational equipment on the ground.
- **Nonprecision Approach Procedures**—Nonprecision approach procedures give only horizontal guidance. Pilots must rely upon other means (other navigation aids on or off the airport and/or radar control) to determine when to descend to a lower altitude along the approach course. Historically, nonprecision approaches required installation of navigational equipment on the ground at the airport or in the vicinity. More recently, stand-alone GPS-based nonprecision approaches have come into use.

Precision approach procedures typically allow lower approach minimums than do nonprecision approach procedures. Most precision approach procedures allow aircraft to land with weather conditions as low as a 200-foot cloud ceiling and a ½-mile visibility. Some major airline airports have navigational aids which enable suitably equipped aircraft to land with *zero-zero* conditions. Good minimums for nonprecision approach procedures are generally double those typical of a precision approach procedure.

Circle-to-land procedures can result in aircraft overflights of areas adjacent to and near the ends of runways which are seldom overflown under regular visual flight conditions. Also, these overflights may be at altitudes well below the normal traffic pattern altitude. The noise and safety implications of circle-to-land maneuvers may be worth special consideration in land use planning around airports where such procedures are common.

Instrument approach procedures are divided into as many as four segments: *initial*, *intermediate*, *final*, and *missed*. The initial and intermediate approach segments serve to guide the aircraft from major air routes to the airport vicinity. Once an aircraft is established on the final approach course, it generally is aligned with the runway and is at a precise altitude. Aircraft fly the final approach segment until reaching the specified minimum altitude at which point, if the runway is visible, the aircraft either proceeds straight ahead to the runway or circles to land on another runway. The missed approach segment of the procedure is utilized if the runway is not visible when the aircraft reaches a predetermined position (indicated by navigational aids or timing) and minimum altitude or the pilot elects to abandon the approach earlier. Missed approach procedures enable the aircraft to climb back to a safe altitude and then either wait for weather conditions to improve or proceed to another airport.

Until the mid 1990s, all instrument approach procedures relied upon ground-based navigational aids. Since that time, procedures utilizing GPS have come increasingly into use. Initially, all GPS procedures were "overlays"—near duplicates of already existing ground-based procedures. More recently, procedures based solely upon GPS have been established. To date, all GPS procedures are nonprecision (providing horizontal guidance only). Ultimately, GPS has the potential to allow establishment of new instrument approach procedures with lower minimums or even curved approach paths. Another key advantage of GPS approach procedures is that they do not require installation of on-ground navigational aids. Runways for which ground-based procedures are not technically practical or cost-effective (because of relatively low activity levels) thus may be capable of accommodating a GPS-based approach.

Despite this potential, it should be realized that, even with GPS, every runway will not become an instrument runway, let alone a precision instrument runway. The FAA has adopted minimum design criteria for runways to support various categories of instrument approach procedures (whether GPS or otherwise). For example, the minimum runway length requirement (as of late 2001) is 3,200 feet for a nonprecision approach. Additionally, lateral setback distances from the runway and the presence of obstacles in the approach and missed approach path are major determinants of the visibility and descent minimums that an approach can have.

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GUIDANCE
Even though GPS may enable many runways currently without an instrument approach procedure to have one in the future, ALUCs cannot necessarily assume this will occur for any particular runway. ALUCs are limited by state law to basing their compatibility plans on master plans or layout plans adopted by airport proprietors. Therefore, unless the adopted plan indicates a runway to be a future instrument runway or the instrument procedure already exists, ALUCs should not base their plans on the possibility that a procedure will be created.

Instrument Departure Procedures

All airports with instrument approach capabilities also have published instrument departure procedures. These procedures enable aircraft to depart an airport and climb to en route airspace. Departure procedures are usually less complex than approach procedures and often do not depend upon on-airport navigational aids. For airline and charter aircraft operations, certain minimum visibility conditions must be met before the aircraft can take off. No minimums are set for operations by private aircraft operating under Federal Aviation Regulations Part 91. Also, instrument departures are permitted from any airport, even those without an instrument approach procedure.

Airport-Related Factors

Adjustments to standard traffic patterns frequently are made to reflect specific conditions at individual airports. Airports where multiple runways are simultaneously used may limit the pattern locations of individual runways in order to avoid air traffic conflicts. Similarly, when two or more airports are situated close together, limitations on their traffic pattern locations may be necessary.

High terrain on one side of an airport is another local condition which may dictate establishment of a right-hand pattern to a runway. Finally, the locations of traffic patterns and flight routes to and from an airport are sometimes defined so as to minimize aircraft overflight of residential or other noise-sensitive land uses.

Specialized Aircraft Flight Routes

In addition to the common arrival and departure flight routes flown by most aircraft, some airports have activity by specialized aircraft which may have their own particular routes.

Helicopter Flight Patterns

Normal flight patterns for helicopters are the same as those for airplanes in certain ways and are different in others. Most of the differences result from the distinct operating characteristics of helicopters.

- **Visual Flight Rules**—Helicopter flight under VFR conditions involves significant differences from airplane flight. For example, en route altitude is generally lower for helicopter flights than it is for airplanes. Federal Aviation Regulations Part 91 establishes the minimum en route altitude for all aircraft at 1,000 feet over urban areas and generally 500 feet over less populated locations. Helicopters, however, may be operated at less than these minimums if "the operation is conducted without hazard to persons or property on the surface."

  The FAA has not established a standard airport traffic pattern for helicopters comparable to that for airplanes. FAR Part 91 dictates only that helicopters should "avoid the flow of fixed-wing traffic." This is often accomplished by flying both at a lower altitude than the airplane traffic pattern and along different routes. Also, many airports and heliports have adopted official or unofficial helicopter approach and departure routes.

  Because helicopters require little or no landing or takeoff roll along the ground the way airplanes do, they can approach or depart a landing/takeoff site from virtually any direction when not limited by obstacles, established procedures, or other factors. Given the choice, helicopters, like airplanes, will land and take off as closely into the direction of the wind as possible. Helicopter landing approach and takeoff climb angles are comparatively steeper, however. Also, the length of these segments can be much shorter than needed for airplanes.

- **Instrument Flight Rules**—Under instrument weather conditions, helicopters mostly follow the same flight rules as airplanes. At airports, for example, properly equipped helicopters can use the same instrument approach and departure procedures as those flown by airplanes. Some helicopter facilities, however, may have instrument procedures exclusively for helicopter use.

Fire Attack Aircraft

Fire attack aircraft operated at many airports in California often utilize special flight tracks not normally followed by other types of aircraft. For example, fire attack aircraft sometimes will make a low pass over the runway prior to landing (primarily at a nontowered airport) or will circle back over the airport to gain altitude on departure. Another common procedure is for these aircraft to take off and land in opposite directions on the same runway. This is particularly common when the fire attack reload base is at one end of the runway or if dictated by terrain or land use considerations.

Agricultural Aircraft

In agricultural locations, agricultural *crop duster* aircraft often are the principal contributors to an airport's overall noise impact. Agricultural aircraft noise differs from that of other aircraft and is difficult to accurately portray in airport noise contours. A key factor is that these aircraft seldom climb to normal traffic pattern altitudes and they often make turns at low altitudes close to the runway.

Other Factors Affecting Airport Noise Levels

Although aircraft characteristics and flight routes are the principal determinants of airport noise impacts, other factors have noteworthy contributing roles.

Ground Operations

Although airborne aircraft operations are the primary source of aircraft noise in the vicinity of an airport, ground operations can also produce significant impacts under certain circumstances. Particular locations of ground operation noise include:

- **On the Runway**—Significant noise levels are generated behind an aircraft, especially a jet aircraft, as full engine thrust is produced during acceleration to takeoff. (More specifically, the highest noise levels are experienced at a 15 to 45 angle from the aircraft path; directly behind the aircraft is a zone of relative quiet.) On landing roll-out, power settings on most aircraft are low and the noise is comparatively minimal. The one significant exception is when jet aircraft use reverse thrust to decelerate after landing. This action can produce high noise levels in front and to the sides of the aircraft. (Note: reverse thrust noise is included in standard Integrated Noise Model computations.)
- **Taxiing**—Aircraft mostly use low power settings when taxiing between parking locations and a runway. For most aircraft, the resulting noise levels are minimal and not a factor off the airport property. There are exceptions, however. For example, aircraft require added power to begin moving when stopped. Also, large aircraft need to apply moderate power to engines on one side in order to turn while taxiing at low speeds. With propeller airplanes, moderately high engine power is briefly necessary to start the engine. Noise levels increase correspondingly for these few moments.
- **At Runway Holding Bays**—Pre-flight engine run-ups by piston aircraft are usually conducted at holding bays or other locations near the ends of run-

Airport land use commissions seldom adopt land use compatibility criteria which specifically consider noise from aircraft ground operations not on the runway. Nevertheless, these noise sources can be significant in locations immediately adjacent to an airport. INM now allows analysis of aircraft run-up noise.

ways. Many people perceive the noise from pre-flight run-ups of propeller-aircraft engines to be more annoying than the noise from overflights, even if the sounds have equal loudness. Part of the reason for this greater annoyance is that run-up noise is thought to be (although it is not) less necessary and more under the control of the aircraft operator. For land uses near the end of a runway, run-up noise can be louder and more prolonged than overflight noise. This is especially true when a runway is used predominantly in one direction. The runway end which is used for landings—when aircraft are typically the quietest—is also the end at which pre-flight engine run-ups are normally conducted.

➤ **At Airline Terminals**—Activity around airline terminals can be a noticeable source of noise. Auxiliary power units on board jet aircraft (used for cabin temperature control, to operate electrical equipment, etc.) are one such source. These noise sources can be bothersome at airports where terminal areas are situated close to noise-sensitive land uses.

➤ **Aircraft Maintenance Facilities**—Maintenance testing of aircraft engines requires the use of high power settings and resulting noise levels. This activity may occur in or near airline or fixed base operations maintenance hangars or sometimes at other locations on an airport. At airports where frequent engine testing creates significant noise impacts on nearby land uses, construction of noise barriers or testing enclosures (sometimes called "hush houses") has become necessary.

Other Variables

It should be noted that the cumulative noise level contours which ALUCs use for land use compatibility planning purposes normally do not take into account variables such as these. Unless special steps are taken to calibrate the noise contours for a particular airport with actual noise measurements taken at that airport, the contours will reflect conditions considered average for all airports.

The noise levels experienced on the ground as an aircraft flies over are primarily dependent upon the inherent loudness of the aircraft, the aircraft's altitude, and the horizontal distance between the measuring site and the aircraft flight track. Other variables are also important, however.

➤ **Pilot Technique**—An important variable in aircraft noise is the pilot. Depending upon the techniques that the pilot employs, the same aircraft can generate significantly different noise levels. Conditions which produce some of the greatest noise variations include:

- The angle of climb while on takeoff (also affected by aircraft payload, air temperature, and wind);
- Power adjustments during takeoff;
- The propeller pitch setting on airplanes with variable pitch propellers, especially at high takeoff power settings;
- Flap settings (especially during landings by large aircraft); and
- The airspeed and descent rate relationships that determine the extent of helicopter blade slap during landing operations.

Pilot awareness of the aircraft configurations that create abnormally high noise levels can be a significant factor in helping to reduce actual airport noise impacts.

➤ **Air Temperature**—Aircraft engines, both piston and turbine, operate less efficiently when temperatures are high. The lower power results in reduced climb rates. For propeller airplanes, somewhat higher noise levels may result. However, for jets, the lower power also results in lower noise emissions, thus essentially cancelling out the effect of reduced climb rates.

➤ **Sound Wave Reflection**—The presence of nearby structures or steep terrain can cause sound wave reflections which may locally increase noise levels. Water or hard ground surfaces can particularly contribute to such occurrences. Certain meteorological conditions—such as a temperature inversion layer—also can reflect sound back to the ground, resulting in higher noise levels.

➤ **Height of Terrain**—Rising or falling terrain changes the distance between an aircraft and people on the ground relative to the flat ground assumed in standard INM calculations. These changes in turn increase or reduce the actual sound levels experienced on the ground compared to the levels calculated by the noise model.

The FAA's Integrated Noise Model version 6.0 allows assessment of the effects of elevation variations.

AIRPORT NOISE METRICS

Measurement of sound is a relatively straightforward and objective process. Environmental noise, however, is comprised of a multitude of varying sounds having different magnitudes, frequencies, and durations, and stemming from different sources. Moreover, to be useful, measures of environmental noise must take into account the ways in which noise affects people.

Metric: A standard or scale of measurement.

In many communities, particularly urban communities, aircraft and other modes of transportation constitute the most predominant sources of noise. Over the years, a variety of noise metrics have been devised in order to assess these forms of noise. Some of these metrics are general-purpose and can be applied to almost any noise source. Others are intended more specifically for measuring aircraft noise and particularly noise associated with aircraft operations to and from airports. These noise metrics can be grouped according to whether they measure the sound level of a single event or are cumulative measures of many events. Essentially all noise description metrics employ a logarithmic scale and the measurement units are expressed in decibels (dB). An A-weighted decibel scale (see Table 6A) is generally used.

Each of these metrics has notable advantages and disadvantages which differ depending upon the purpose of the noise measurement. These tradeoffs are discussed in Chapter 7. The emphasis in the discussion here is on describing the various metrics available to airports and land use planners.

Single-Event Metrics

The sound level associated with an individual aircraft flying nearby (see Figure 6F) can be characterized as:

- Beginning at some point when the sound can be distinguished above a threshold or ambient sound level;
- Reaching a maximum level; then
- Diminishing until it is no longer distinct.

Ambient Noise Level: The background noise level absent any readily distinguishable sounds.

Instantaneous Sound Levels

Sound levels can be measured on a continuous basis for each instant during this cycle. A significant point is the maximum sound level attained (L_{max}). L_{max} is an important determinant of whether speech interference may occur.

Single Event Energy

The *SENEL* metric used in California is virtually identical to the *Sound Exposure Level* (SEL) metric used by the Federal Aviation Administration and other federal agencies.

The limitation of an instantaneous sound level measurement is that it provides no information regarding the duration of a sound. Two different aircraft overflights thus can produce vastly different total amounts of sound energy at a given point on the ground depending upon how quickly the aircraft pass by. To compare the total sound produced by individual aircraft flyovers, a reference time of one second is used. In other words, this measurement method indicates the level of a continuous one-second sound which contains the same amount of energy as the complete noise event. The resulting noise metric is called *Single Event Noise Exposure Level* (SENEL).

Figure 6F illustrates the relationship between L_{max} and SENEL for a typical aircraft noise event. Because aircraft noise events last more than one second, SENEL values are higher than the L_{max} recorded for any individual event. The relationship between SENEL and L_{max} is not constant, however. For most aircraft noise events, SENEL is about 5 to 10 dB higher than L_{max}; the shorter the noise event is, the closer the two numbers will be.

Cumulative Noise Metrics

Various other cumulative noise metrics exist in addition to the ones mentioned here. Some are used for measuring other aspects of noise (the amount of time noise exceeds a certain level, for example) or noise from sources other than airports. Others were created as communications tools rather than for policy making purposes. Still others are found primarily in other countries. None of these metrics are considered applicable to airport land use compatibility planning in California.

In order to provide a single measure of continuous or multiple noise events over an extended period of time, a variety of cumulative noise level metrics have been devised. Most of these metrics result in a weighted average measurement of noise over time.

Equivalent Sound Level

A standard measure of sound level averaged over a specified period of time is the *Equivalent Sound Level* (abbreviated L_{eq}). This metric indicates the constant sound level in decibels which would produce the same amount of sound energy as a series of events having fluctuating sound levels. The more closely spaced the noise events over the entire measurement period, the closer L_{eq} will come to L_{max}. This is the case for noise from a busy highway, for example. For infrequent noise events, such as at a low-activity general aviation airport, L_{eq} may not be much higher than the ambient noise level.

Time-Weighted Cumulative Noise Metrics

The remainder of this *Handbook* primarily refers to cumulative noise metrics in term of CNEL rather than DNL in that the former is the metric used in most California state noise regulations including those for airports.

Undoubtedly the most widely used metrics for assessment of airport noise levels are time-weighted cumulative noise metrics. These types of metrics include the *Community Noise Equivalent Level* (CNEL) used in California and the *Day-Night Average Sound Level* (abbreviated as DNL, but symbolized in formulas as L_{dn}) adopted by the Environmental Protection Agency and the Federal Aviation Administration and used elsewhere in the United States.

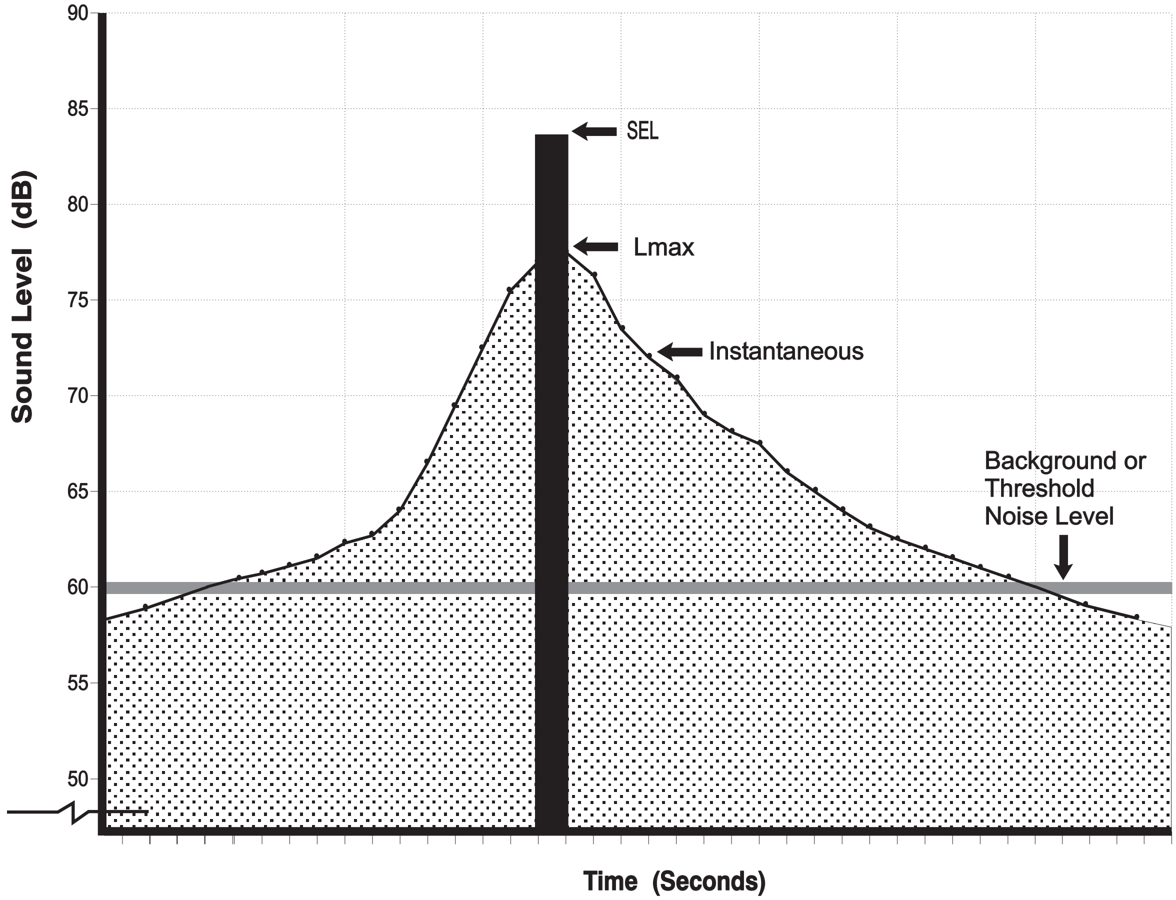

FIGURE 6F

Typical Aircraft Noise Event

Both metrics are similar to the Equivalent Sound Level (Leq) except that they compensate for the widely assumed increase in people's sensitivity to noise during nighttime hours. Each aircraft operation occurring between 10:00 p.m. and 7:00 a.m. is treated as if it were 10 operations. Similarly, CNEL (but not DNL) includes a penalty weighting for operations taking place between 7:00 and 10:00 p.m. in the evening. Each aircraft operation during these hours is counted as if it were three operations. Logarithmically, these multipliers are the equivalent of adding 10 dB to the noise level of each nighttime operation and 4.77 dB to the noise level of each evening operation. These noise level penalties are intended to correspond to the drop in background noise level which studies have found takes place from daytime to evening and nighttime in a typical community. The evening and nighttime decrease in ambient sound levels—from both outdoor and indoor sources—is commonly considered to be the principal explanation for people's heightened sensitivity to noises during these periods.

CNEL values are normally depicted by a series of contours representing points of equal noise exposure in 5 dB increments (see example in Figure 6G). Specialized computer programs—as described in the next section—are normally used for calculation of noise contours.

Calculation of Airport Noise Contours

When developing or updating compatibility plans, ALUCs (or their staff or consultants) sometimes need to prepare airport noise contours. Even when creation of noise contours is not necessary as part of a compatibility planning process, it is important that ALUCs and their staffs understand the factors involved.

Just as the metrics created for describing airport noise have evolved over the years, so have the means available for calculating current and future noise levels around airports. Today, highly sophisticated computer models are commonly used to carry out the noise calculations. Still, as precise as these models can be, they depend upon the accuracy of the data entered into them. These topics are discussed in the text which follows.

Aircraft Noise Models

Integrated Noise Model

Anyone can obtain the INM software through the FAA. However, most airports and ALUCs retain consultants to prepare noise analyses. Major airports commonly have their own staff trained in use of the program.

In the U.S., by far the most commonly used aircraft noise model is the Federal Aviation Administration's Integrated Noise Model (INM) computer program. INM was developed by the FAA as a means of standardizing the assessment of aircraft noise levels in the vicinity of airports. The original INM program dates back to 1978. As of late 2001, the most recent version is 6.0 which was introduced in 1999. Each iteration of the program has added to its sophistication, allowing noise contours to be computed more efficiently and more accurately. However, one effect of the upgrading of the noise calculation algorithms at the core of the program has been that identical input data may result in slightly different output contours than produced by earlier versions.

The INM is capable of providing output in a variety of formats and metrics. Noise contours can be produced using CNEL, DNL, or any of several other cumulative noise metrics. Single-event contours can also be run. Finally, detailed data for a point or grid of points can be produced.

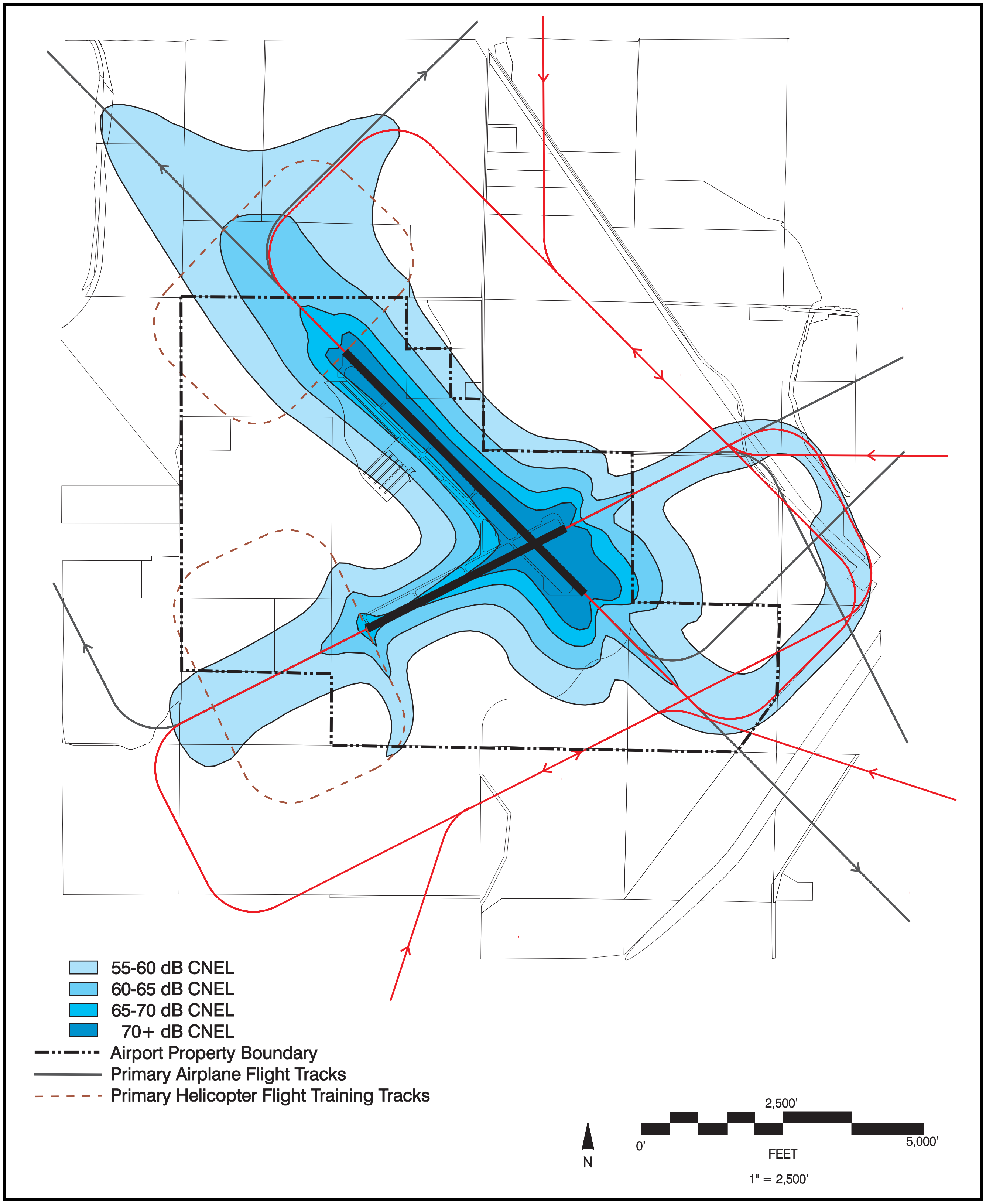

FIGURE 6G

Example of Airport Noise Contours

Other Noise Models

While INM has widespread general utility, two other noise models have been created for use in more specialized circumstances. (Also, other countries have developed their own variations of noise models.)

➤ **Helicopter Noise Model**—For calculation of noise contours at heliports, the FAA has developed a separate program—the *Helicopter Noise Model* (HNM). This model, last updated in 1994, includes data for 16 types of helicopters. However, its lack of static mode flight data for most of the helicopters in the database limits HNM's usefulness in modeling hover noise levels which are critical to evaluation of noise exposures close to heliports and helipads. Also, HNM does not allow user modifications to the database.

Because NOISEMAP includes data for military helicopters similar to ones in civilian use, the program serves as an alternative method for modeling heliport noise impacts.

➤ **NOISEMAP**—The current U.S. Air Force NOISEMAP model has capabilities similar to the latest version of INM, but is designed for use at military aviation facilities or civil airports with a substantial amount of military aircraft operations. The aircraft noise database in NOISEMAP consists solely of military aircraft, but civil aircraft can be added using the INM database. The noise computation algorithms are slightly different between the two models, but the output noise contours are very similar.

Sources of Aircraft Noise Model Input Data

In order to calculate noise contours or other noise impact information, INM and the other noise models require several types of data. Some of the data is built into the model database, although (except for HNM) it can be modified by the user. Other data must be entered for each individual noise study. Still other types of data can be entered to refine the analyses, but are not required.

Built-In Data

The database built into INM consists primarily of aircraft-related data. Information is included on over 100 different types of airplanes. The emphasis, though, is on airline and military aircraft. General aviation is comparatively less represented, especially with regard to relatively new aircraft models. For each of the aircraft in the database, standardized data is provided for:

- Performance characteristics (takeoff distance, climb rates, etc.);
- Power settings used at various stages of landing or takeoff; and
- For each power setting, the amount of noise measured at various distances from the aircraft.

Table 6C provides additional background information about aircraft noise and operations monitoring systems.

The database reflects average operating conditions for each aircraft type. In most cases this data is used directly when calculating noise contours. INM also has the capability of accepting user input data to better fit known variations for a particular aircraft or airport. For example, adjustments or "calibration" of the standard aircraft parameters can be done based upon data obtained from noise monitoring systems. Production of noise contours does not require use of noise monitors, however.

History

Airport noise and operations monitoring systems have been installed at California airports since the 1970s. The earliest systems measured aircraft noise levels at fixed positions, separating aircraft noise events from other noise sources primarily by their isolation from such sources, and the use of threshold values for noise levels and event duration. Other noise event parameters were evaluated during data analysis to improve discrimination of aircraft noise events. Later systems relied on airport staff input of FAA flight strips (which the FAA did not make available until at least 14 days after the flights). Using a computer, sequential noise events were then matched to the reported FAA takeoff release times. In this manner, aircraft noise events were reasonably well separated from other noise sources and it was possible to determine the noise levels produced by individual aircraft.

Over time, noise and operations monitoring systems have taken advantage of better computers and of access to aircraft flight data directly from FAA data disks and computer downloads, use of passive radar systems to gather data without the need for FAA cooperation (except the flight strips), and most recently, direct connection to the FAA TRACON radar system using an FAA-approved "gateway."

Present-Day Systems

Today, several major California airports have fully integrated noise and operations data collection and analysis systems which allow rapid matching of aircraft noise events, specific flights, and their flight paths. Other, typically less busy, airports have systems which monitor noise levels, without access to FAA radar data. In such systems, recordings of radio transmissions by the FAA Tower and the aircraft are used to correlate noise events to specific flights.

Permanent aircraft noise and operations monitoring systems provide a highly credible database of noise level and operational data including:

- Long-term measurements of cumulative noise levels
- Statistically valid distributions of measured single-event noise levels by aircraft type and operator
- Precise definition of flight tracks and areas of aircraft overflights
- Census of aircraft types and operations
- Flight profiles
- Adherence to established flight procedures
- Variations in noise levels and operational procedures over time
- Changes in noise levels due to changes in operations
- Identification of aircraft flights and noise levels associated with complaints and political concerns
- Accurate input data for the INM
- Validation of INM-predicted CNEL contours

Although each system has distinct capabilities, noise and operations monitoring systems will typically be capable of producing a wide range of standard or customized statistical analyses and maps. Most systems either utilize or can be integrated with geographic information system (GIS) databases. All of these systems enable precise judging of changes in noise levels and compliance with the established noise emissions criteria. Additionally, by accurately defining aircraft noise exposures, they facilitate justification and implementation of noise mitigation programs such as sound insulation or property acquisition.

Although permanent noise and operations monitoring systems are unsurpassed as an objective method of providing current airport noise data, a major limitation is their cost. Systems such as these can range from about $500,000 to as much as $2.0 million.

The high costs limit the practicality of permanent systems for smaller airports. At these facilities, noise measurements can be made using portable monitoring units set to discriminate between aircraft and nonaircraft noise levels in the same manner as the earliest systems. Noise sampling techniques may be used to provide reasonable estimates of cumulative noise exposures over longer periods and single-event data can be collected for comparison to noise levels predicted using the INM. In addition, short-term radar data, or observations of aircraft flight paths in the field or at the radar scope, can be used to develop reasonable assumptions for standard aircraft flight tracks.

While not as sophisticated as the permanent systems, even the portable units can serve an important function of all monitoring systems. They serve as an essential source of information with which to respond to public queries and concerns over airport noise.

TABLE 6C

Noise and Operations Monitoring Systems

User-Provided Data

The user-provided data critical to operation of INM consists of defining where aircraft fly and how often. An extensive amount of data is usually available for major airline airports and other airports situated in the surrounding metropolitan area. For airports in outlying or rural areas, solid data may be scarce and use of estimates may become necessary.

Inputs to CNEL noise contour calculation include:

- Runway system configuration and runway lengths.
- The geometry of common aircraft flight tracks.
- The standard approach slope used for each runway.
- The number of operations by aircraft type or group.
- Runway utilization distribution by aircraft type and time of day.
- The distribution of operations by time of day for each type of aircraft.
- The distribution of operations for each flight track.

Specific types of data needed by INM are listed in the adjacent sidebar. Potential sources for this data include the following:

- **Radar Flight Track Data**—For airports covered by FAA terminal radar control (TRACON) facilities, recorded flight track data is an ideal source of information on where aircraft fly. Not only the path of the aircraft along the ground, but also the altitude and the type of aircraft can be identified. Noise models, however, are not capable of working with an indefinite number of flight tracks. In practice, past versions of INM required simplification of the radar data into a relatively limited number of tracks. Recent versions of the software allow for some refinement of this process—a set of dispersed subtracks offset horizontally (but not in altitude) from the primary tracks can now be modeled.
- **Control Tower Counts of Aircraft Operations**—At airports having functioning traffic control towers, tower personnel maintain complete data on the number of aircraft operations. This data categorizes the operations as to whether they were conducted by air carrier, air taxi, general aviation, or military aircraft (a note of caution here: air carrier and air taxi counts may include operations other than by scheduled airlines). Also counted are itinerant (headed to or from other airports) versus local (consisting mostly of flight training "touch-and-go") operations. Tower count data can usually be obtained from airport management or directly from the FAA and is also available via the Internet.
- **Automated Aircraft Operations Counter Data**—Because only the busiest airports have control towers, the Division of Aeronautics has established a program for obtaining activity data for other facilities using automated aircraft operations counters. Present counters work acoustically by counting the number of noise events (usually on an hourly basis) which exceed a set threshold sound level. By placing the microphone at a point close to where aircraft take off, the threshold level can be set such that aircraft takeoffs are the only noise sources to trigger the counter. A limitation of counter data is that it typically is gathered on a sampling rather than complete count basis. Annual data must be inferred from the samples. To increase the accuracy, counts are normally done during several times of the year.
- **Airport Management Records**—Neither control tower nor automated counter data fully identify the types of aircraft operations. Additional data needs to be obtained from other sources. Information on numbers of scheduled airline flights, air cargo aircraft operations, fire attack aircraft missions, and other distinct forms of aircraft activity are often maintained

MEASURING AIRPORT NOISE CHAPTER 6

by airport management, particularly if landing fees are collected from these users. Airport management also may have information on the types of aircraft based at the airport which can be used to help estimate the mix of aircraft operations.

- **Wind Data**—Wind direction data gathered at the airport in question or at a nearby location can be useful in estimating the percentage of usage of each of the airport's runways.
- **Interviews with Airport Personnel**—Individuals who regularly operate or observe aircraft at the airport comprise a final source of valuable, although qualitative, information on aircraft types, runway usage, flight tracks, time of day distribution, and other inputs to noise modeling. Interviews with control tower staff, flight instructors, and others can help fill the gaps in quantitative data.
- **Projected Activity**—The data sources listed above are all potentially useful in preparation of noise contours representing current airport activity. To develop contours depicting projected future noise impacts, forecasts of future activity are necessary. Additionally, assumptions must be made regarding future changes in the aircraft fleet mix, runway utilization, and other noise model input data.

Chapter 7 contains a discussion of forecasts and other factors to consider in development of projected noise impact contours.

Optional Data

To refine the precision of noise contours, the latest versions of INM allow entry of terrain data. Whereas earlier versions assumed that the airport and surrounding areas were all on level ground, this capability enables the effects of increased or decreased distances between the aircraft and the ground to be calculated. (The effects of shielding or reverberation produced by the terrain are not taken into account, however.)

Another form of data which can be entered into the program on an optional basis is census data. Although this information has no effect on the contours, its entry can facilitate evaluation of the numbers of people impacted by various noise levels or aircraft operational scenarios.

Limitations of Airport Noise Contour Modeling

Despite the increasing sophistication and accuracy of airport noise models, several limitations are important to note.

- **Aircraft Database Limitations**—Even though additional aircraft have been added to the database with each version of the program, INM (as well as the other noise models) tend to be slow in including the newest models of aircraft. This is particularly the case with regard to late model general aviation jet aircraft. Often it is necessary to substitute similar aircraft. The INM database also lacks information on helicopters and specialized aircraft such as agricultural aircraft. Lastly, all of the databases include only existing aircraft. When modeling projections of noise impacts more than five or so years in the future, the quietest existing aircraft are typically assumed to be representative of average future aircraft.

- **Flight Tracks**—Close to the ends of runways, nearly all aircraft flight tracks are aligned with the runway, especially on arrivals or on departures from a short runway. The greater the distance from the runway ends, the more the tracks disperse. The accuracy of noise contours in these areas depends greatly upon the number and location of flight tracks entered into the noise model. If too few flight tracks are defined, the noise contours will tend to take on a spiky rather than usually more realistic bulbous shape. This is particularly the case with general aviation aircraft in that their flight tracks ordinarily vary quite widely. Even airline aircraft following instrument procedures have a noticeable divergence in their flight tracks, although certain flight corridors are normally evident. On the other hand, attempts to model a large number of flight tracks can be difficult and, if little is know as to their precise location or frequency of use, not necessarily more accurate. The recent enhancement of INM allowing modeling of dispersed subtracks adjacent to the primary tracks can help improve the realism of noise contours.

- **Helicopter Noise**—Because of their separate flight tracks, different operating characteristics, and typically low activity volumes, helicopter operations are often not included in noise contour calculations. However, a simulation of helicopter noise can be included in Integrated Noise Model calculations. Also, the noise impacts of some types of helicopters can be modeled with the separate FAA Helicopter Noise Model (HNM) or the U.S. Air Force NOISEMAP model and the impacts then manually added to airplane impacts calculated with INM.

- **Ground Operations**—As noted previously, various types of aircraft ground operations can be significant noise sources at some airports. Although recent versions of INM allow some of this activity to be modeled (specifically, run-up operations), this is seldom done unless a problem with noise from this source is known to exist.

- **Local Environmental Conditions**—The noise calculation algorithms built into the model assume an average set of physical and atmospheric conditions in the area surrounding an airport. Thus, localized factors such as reflection or diffraction of sound off of or around terrain or buildings are not considered. Similarly, local atmospheric conditions—such as temperature, humidity, wind, and cloud cover—may result in day-to-day variations from the predicted annual average noise levels.

- **Precision**—Because of the many variables and assumptions associated with their computation, cumulative noise contours representing existing airport activity are often considered to have a precision of approximately ±3 dB. Greater precision (within ±1 dB) can be obtained at airports where flight track data is available from radar and/or a permanent noise monitoring system is installed. In any case, precision is greatest close to the runway and decreases beyond where flight tracks diverge.

- **Projections of Future Noise Impacts**—As imprecise as modeling of current noise contours can sometimes be, contours representing projections of future noise impacts are inherently even less precise. Uncertainty regarding future aircraft technologies and the timing of when current aircraft models will be phased out of use is one source of imprecision. Perhaps even more unknown is the future number of operations of various aircraft types likely to occur at any particular airport.