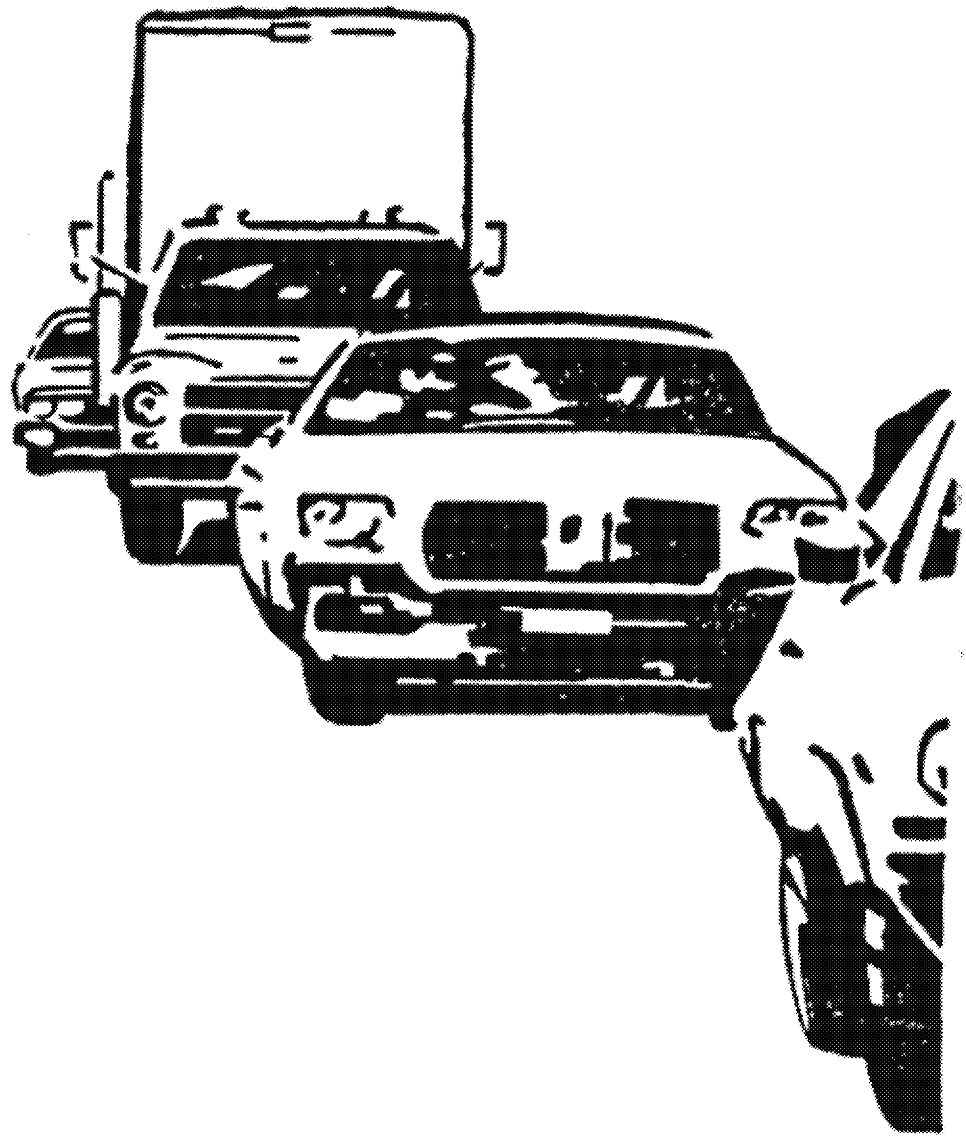
ADVANCED PREDICTION AND ABATEMENT OF HIGHWAY TRAFFIC NOISE



Federal Highway Administration
Office of Environmental Policy
June 1982

(recreated November 2016)

NON-HIGHWAY NOISE SOURCES

INTRODUCTION

It is important to understand the contribution of noise sources other than the highway in order to determine the total noise exposure in an area, for both "existing" and "after" conditions. This understanding permits an estimate of the relative impact of highway noise, and also permits one to evaluate the benefits of highway noise control actions. For example, if aircraft noise exposure is equal to highway noise exposure, reducing highway noise by 15 dB through construction of a noise barrier reduces the total noise level by only 3 dB. Thus, constructing the barrier is not a very cost-effective action. On the other hand, if there is a railroad line adjacent to the highway, it may be possible to develop a noise barrier design which provides shielding to the community for both highway and railroad sources, thus providing a meaningful reduction in the total noise environment if the rail noise exposure is significant.

This section will cover predictions of noise exposure for several common sources at critical receiver locations. Why do we not just measure the noise levels from these sources? Unlike highways, many transportation systems exhibit considerable variability over a 24-hour period, making measurement of the noise exposure for just a few key hours unrealistic. Further, for some sources there is considerable variability from day to day, making it difficult to select the proper day for making measurements. Finally, to evaluate "after" conditions, some sources may be expected to change with time, so predictions are necessary for future conditions.

In this section prediction procedures will be provided for general community noise, railroad line operations noise, and the noise of civil aircraft flight operations. Several sources that may occur in a community that will not be covered in this section include industrial noise, construction noise, the noise in the vicinity of railroad yards, and military and general aviation flight operations noise and all aircraft ground operations noise. Many of these sources are quite site specific, and not readily amenable to simplified prediction procedures. In some cases, as for certain industries, noise exposure does not change considerably and determination of levels can be obtained through measurements.

Before we get into the details concerning each prediction method, we must discuss the noise descriptors that will be utilized, so that the noise exposure from each noise source will be dealt with in a similar manner.

The average or equivalent sound level, over a time period T, can be expressed as:

$$L_{eq}(T) = 10 \log \frac{1}{T} \int_T 10^{L(t)/10}\, dt$$

where L_{eq} is the equivalent sound level, in dB, L(t) is the A-weighted instantaneous sound level as a function of time, in dB, and T is the calculation or measurement period. Since the L_{eq} represents the average A-weighted acoustic energy occurring over a time period T, the L_{eq} from several sources can be compared on a common basis, or combined together to provide a total L_{eq} for the noise environment. Many other common Descriptors (such as L_{max}, L_{10}, L_{50}) cannot be combined together in this way. Also, such descriptors are not all meaningful for some sources (such as L_{50} for aircraft). As indicated by the above equation, the equivalent sound level is determined through knowledge of the A-weighted sound level at each moment of time. For many sources where the noise environment consists of a series of discrete single events, separated by periods of time when no noise occurs, a useful measure for calculation purposes is the sound exposure level, SEL. The sound exposure level is defined as follows:

$$SEL = 10 \log \int_{t1}^{t2} 10^{L(t)/10}\, dt$$

where SEL is the sound exposure level, in dB, and t1 and t2 are the times at the beginning and conclusion of the noise event, defined as the times at which the noise level first rises within 10 decibels of the maximum level, and then falls below 10 decibels of the maximum level, respectively. As shown in Figure 4-1, the sound exposure level converts the A-weighted acoustic energy durin6 the noise event into an average value, averaged over a reference duration of 1 second. Then, if there is one such event during time period T, the equivalent sound level during this period can be determined by:

$$L_{eq}(T) = SEL + 10 \log \frac{1}{T}$$

If there are N equal events during time period T, the equivalent level can be described as follows:

$$L_{eq}(T) = SEL + 10 \log \frac{1}{T} + 10 \log N$$

What time period T is most useful for community noise analysis? For T=1, $L_{eq}(1)$ is the hourly equivalent sound level, often used in highway noise analysis, where the hour chosen is the peak or design hour. For T=24, $L_{eq}(24)$ is the 24 hour equivalent sound level. Even more useful than the 24 hour L_{eq} is the day-night sound level, L_{dn}, in dB. The day-night sound level is the same as the 24 hour L_{eq}, except that noise levels occurring during nighttime hours (10 p.m. to 7 a.m.) are increased by 10 dB before averaging to account for people's greater sensitivity to noise during these hours. If the hourly equivalent sound level is known for all 24 hours of the day, the L_{dn} is the energy average of all the 24 L_{eq}' s , with 10 dB added to the 9 L_{eq}'s corresponding to the night hours, before averaging:

$$L_{dn} = 10 \log \frac{1}{24} \sum_{i=1}^{24} 10^{\frac{[L_{eq}\ (1)_i\ + w_i]}{10}}$$

where $w_i = 0$ for i = 1-7, 23, 24

$w_i = 10$ for i = 8-22

Figure 4-2 shows the 24 hourly L_{eq}'s near a roadway plotted as a function of time, with the L_{dn} indicated on the figure.

The day-night sound level is now used for assessing community noise exposure and impact by HID, in its "Noise Assessment Guidelines"; EPA, as the primary measure of community noise exposure; FAA, as the measure for aircraft noise assessment; the military, in its Tri-Services Noise Planning Manual; and NBS, in its Design Guide. Further, in a recent inter-agency agreement, EPA, DOT, HUD, DOD, and the Veteran's Administration recognize and recommend the use of the day-night level for defining land use compatibility guidelines.

Why has L_{dn} become so popular among these government agencies? There are many reasons. The day-night

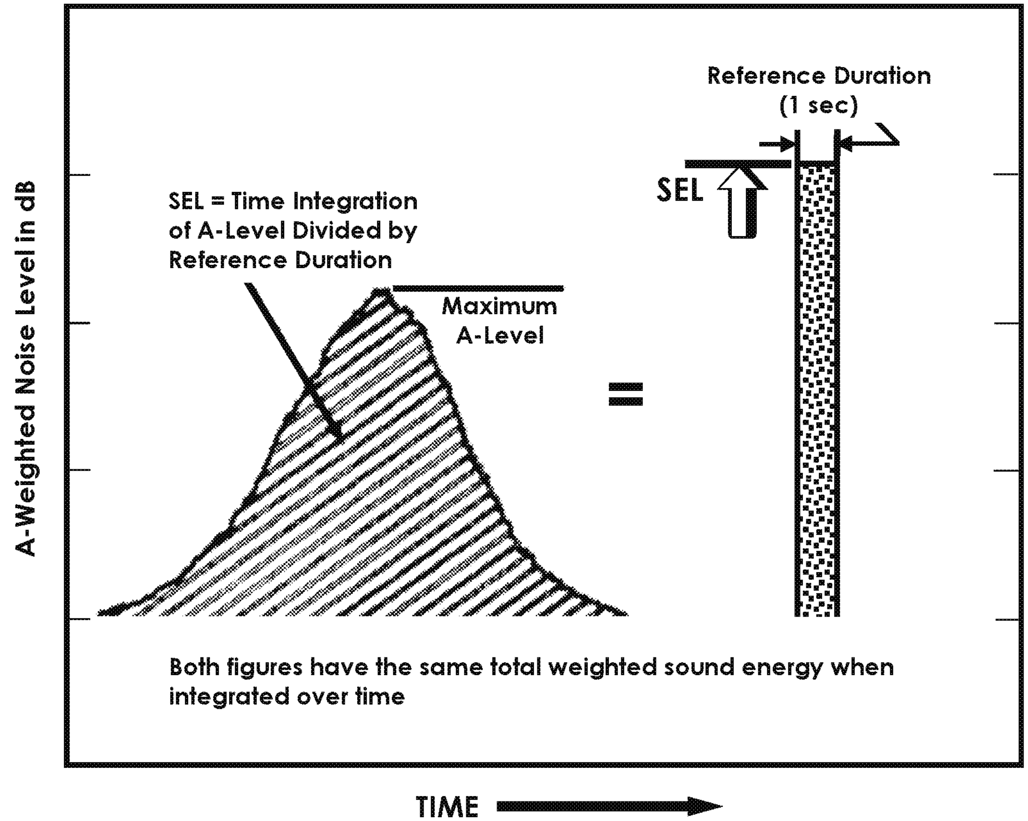


FIGURE 4-1

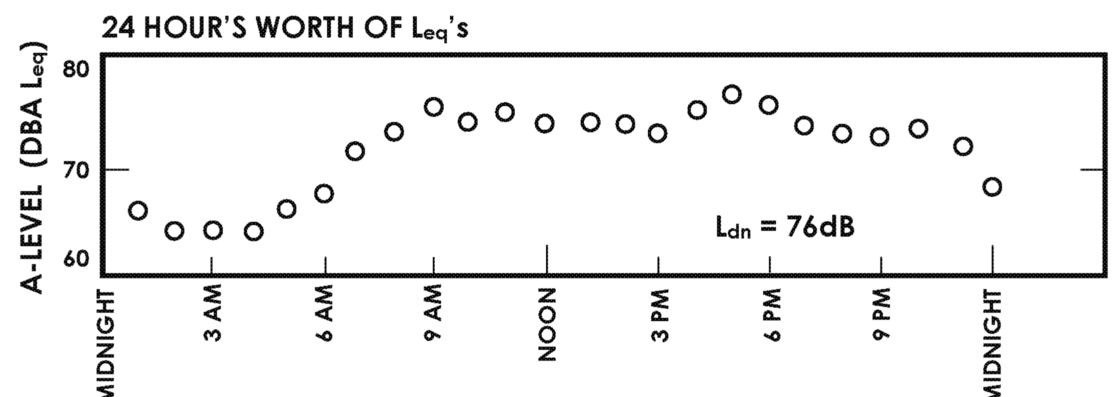


FIGURE 4-2

level correlates well with community response, and this correlation holds true for many different sources. See, for example, Figure 4-3, in which the day-night level is plotted as a function of the percentage of the community highly annoyed by different noise sources, for sources ranging from airports to roadways to railroad lines. Further, the L_{dn} is relatively easy to measure for many sources, with today's sophisticated measurement instrumentation. Finally, from many sources the L_{dn} is relatively easy to predict as will be seen in the following sections.

COMMUNITY NOISE

Model Development

It has been determined in a number of studies that surface transportation noise is the greatest contributor to environmental noise. Over a large range of population and population densities, several facts concerning transportation are relevant to the development of a noise prediction model. First, motor vehicles are the pre-dominant source of surface transportation noise. Also, the number of automobiles per person is relatively constant, as is the ratio of trucks to automobiles. Further, the usage of vehicles is directly proportional to the population density of an area. Finally, for non-freeway traffic in urban areas the average vehicle speed is generally constant. Since traffic noise is proportional to 10 times the logarithm of the number of vehicles

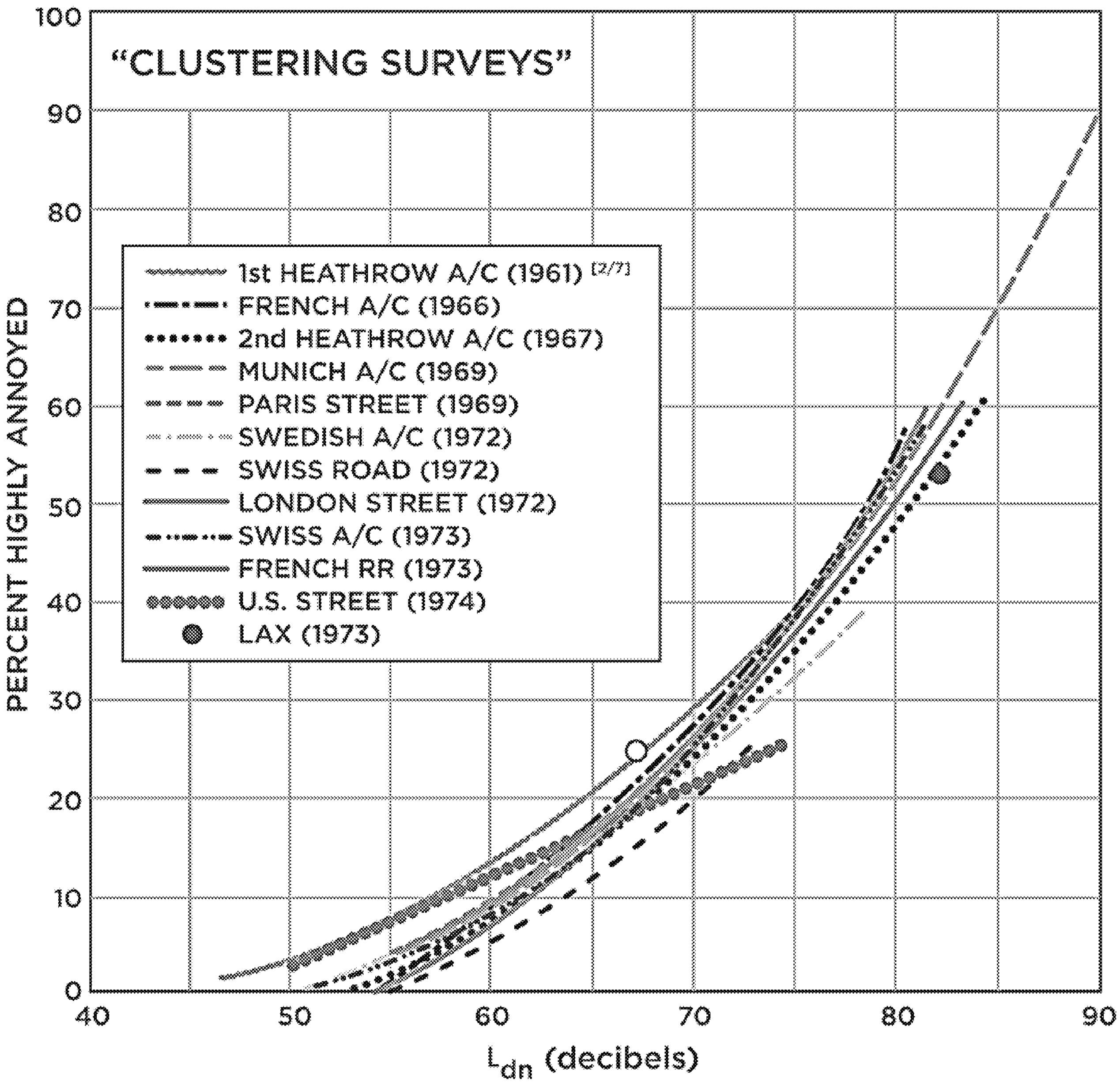


FIGURE 4-3

for a given speed, this leads to the conclusion that community noise is approximately proportional to 10 times the logarithm of the population density in an urbanized area.

Model Va1idation and Application

To test these hypotheses, day-night sound level measurements were obtained at over 100 locations spread across 14 urban areas of the United States (in the regions identified in Figure 4-4). A plot of the measured day-night sound level as a function of the population density of the area is shown in Figure 4-5. A line through these data points takes the form of:

$$\overline{L_{dn}} = 10 \log \rho + 22 \text{ dB}$$

where $\overline{L_{dn}}$ is the average day-night sound level in the area, with a standard deviation of 4 dB, and ρ is the population density of the census tract in people per square mile which contains the measurement location. This equation, then, provides an estimate of the average day-night sound level in an area given knowledge of the area's population density. This day-night sound level is the background existing noise in the community, away from major highways, airports and other site-specific major noise sources. The average value can be assumed to be accurate to within a standard deviation of 4 dB.

RAILROAD LINE OPERATIONS

Comparison With Highway Operations

There are a number of striking similarities between rail operations on railroad lines and highway operations. In both cases, operations occur on fixed paths. Individual vehicles move past an observation point at a relatively constant speed. There are a limited number of vehicle types with relatively similar frequency spectra. Differences between rail and highway operations relate primarily to the noise emission levels of individual vehicles, and the time pattern of the operations. For rail operations, there are fewer vehicles in a given time period, with an irregular pattern throughout the day. (See Fig. 4-6.)

However, since the hourly equivalent level near a highway is determined by averaging the acoustic energy of individual vehicle passbys, and then summing over all vehicles, the hourly equivalent level for railroad operations can be determined in a similar manner. Thus, except for changes in vehicle categories and associated emission levels, we can use the FHWA manual method for rail line operations.

Noise Sources

Rail vehicles can be categorized into two major types: locomotives and rail cars. Diesel-electric locomotives haul over 99% of the trains in the United States. The diesel engine drives an alternator or generator, which powers an electric traction motor on the wheels. There are eight throt-

FIGURE 4-4

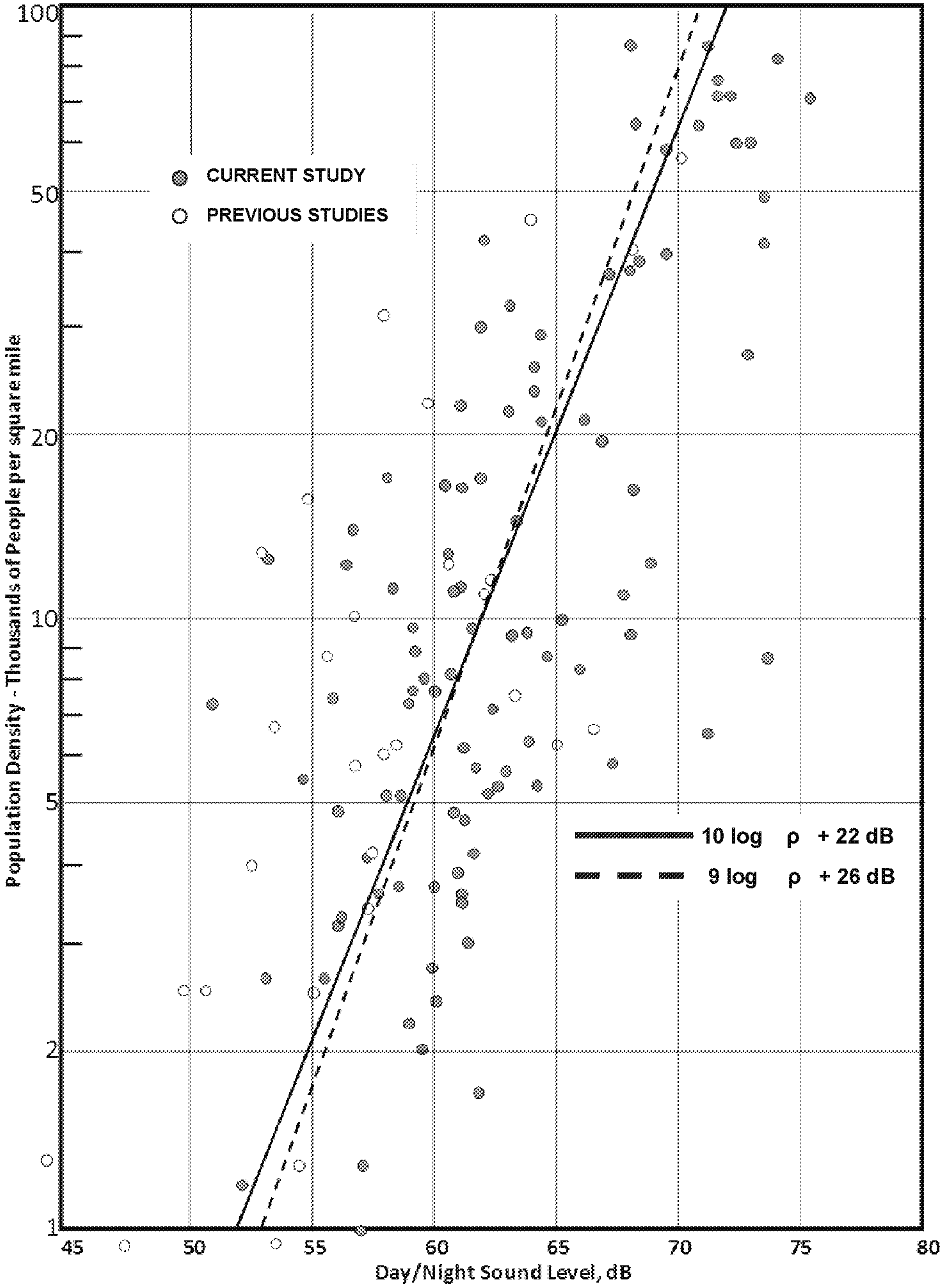


FIGURE 4-5

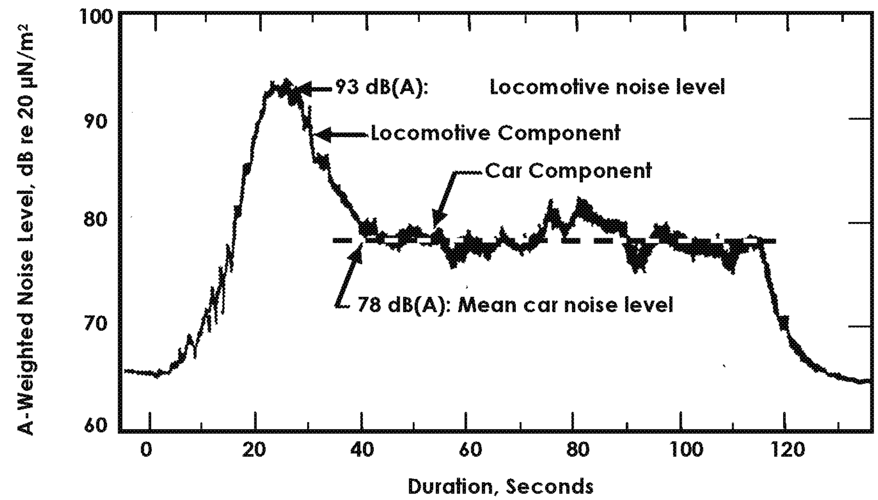


FIGURE 4-6

tle or power settings, in addition to idle. The noise level· varies with throttle setting. The electrical system acts as an automatic transmission: for a given throttle setting, there is constant load for different speeds. Therefore the maximum level is speed-independent. Exhaust noise is the dominant sound.

For rail cars, the wheel/rail interaction is the major source. Resulting noises include the roar, or rolling noise, which increases as 30 log of the speed; impact, or the clickety-clack noise over joints and track irregularities, (jointed rail is 6 dB noisier than continuously welded rail); and squeal, which occurs over tight curves and is a high-pitched sound. Finally, at grade crossings and other selected locations, horn and whistle soundings can be an important source of noise for nearby community residents.

Rail Noise Prediction Method

The steps below permit prediction of rail noise day-night sound level using the FHWA traffic noise prediction model.

1. Categorize all rail vehicles on the track into two categories, diesel locomotives, and rail cars (including freight, passenger, and rapid transit cars).

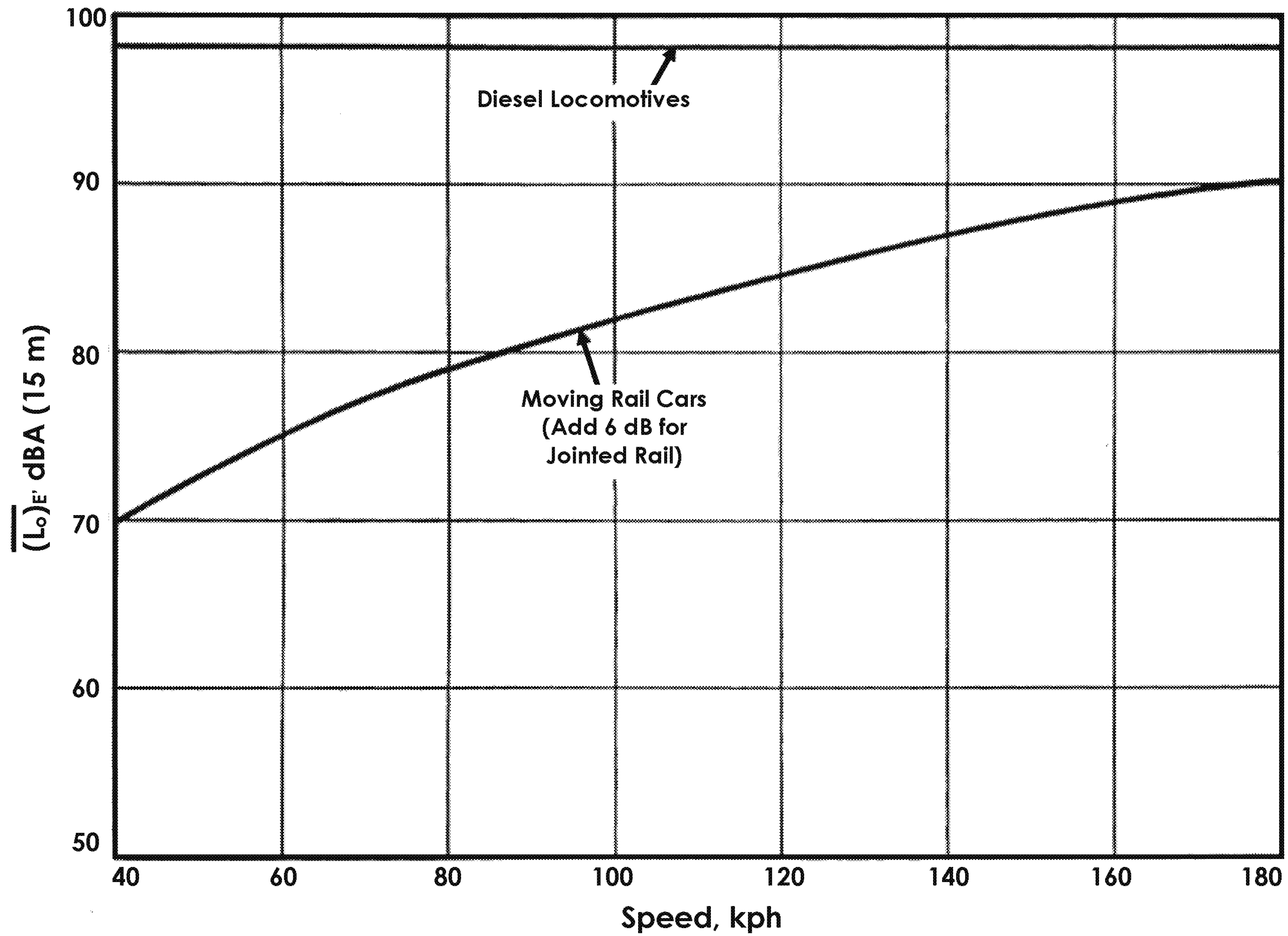
2. For each of these categories, tabulate the number of such vehicles passing by the observer during daytime and nighttime periods, N_d and N_n. Remember that daytime is from 7 a.m. to 10 p.m., and nighttime is from 10 p.m. to 7 a.m.

3. For each category, tabulate the average vehicle speed (note that if there are major differences in speed for the same vehicle category, for example freight trains at 30 mph, passenger trains at 60 mph, both with locomotives and rail cars, divide the category into sub-categories by speed).

4. For each category or sub-category i, determine the effective number of operations, N_{eff}, by adding N_d to 10 times N_n.

5. Use the FHWA traffic noise prediction model, with the following modifications: (a) Use the reference energy mean emission levels for diesel locomotives and railcars, shown in Figure 4-7. (b) Replace N_i with N_{effi}. (c) Replace T=1 hour with T=24 hours, or, equivalently, subtract 13.8 dB. Equation 1 of the FHWA model now becomes:

$$L_{dni} = (L_o)_{E_i} + 10 \log \left(\frac{N_{effi}\ D_o}{S_i}\right) + 10 \log \left(\frac{D_o}{D}\right)^{1+\alpha} - 25 - 13.8$$



100
90
80
70
60
50
Diesel Locomotives
Moving Rail Cars
(Add 6 dB for
Jointed Rail)
$\overline{(L_o)}_E$, dBA (15 m)
40
60
80
100
120
140
160
180
Speed, kph

FIGURE 4-7

The model now predicts L_{dni} for category i of rail vehicles, instead of $L_{eq}(h)_i$ for category i of highway vehicles.

One additional factor must be considered in the estimation of rail line noise. If horns or whistles are sounded in the vicinity of the observer, the resulting noise exposure must be included in the summation of the L_{dni}'s for all categories and sub-categories of vehicles. Since the typical horn or whistle will produce a sound exposure level roughly 10 dB higher than the SEL of a diesel locomotive, the Lan contribution for horns or whistles can be determined as follows:

$$L_{dnhw} = L_{dndl} + 10 + 20 \log \frac{D}{D_{hw}}$$

where L_{dnhw} is the horn/whistle L_{dn} contribution, L_{dndl} is the diesel locomotive L_{dn} contribution, and D_{hw} is the shortest distance from the observer to the location at which the horn or whistle is sounded. From this equation, if D_{hw} is more than 10 times D, the horn or whistle does not contribute to the total L_{dn}.

Except for the horn/whistle L_{dn} contribution, the procedures in the FHWA traffic noise prediction model can be used to estimate any barrier shielding effects, the influence of rows of houses, etc. If the horn/whistle sounds are shielded, estimation of the L_{dn} contribution might best be determined through measurements.

EXAMPLE:

There are ten freight trains daily (including three at night) on a flat, straight track 60 m. from a location of interest. Each train consists of 3 locomotives and 60 rail cars, and travels at 64 kph. The terrain is "soft", and the track has continuously welded rail.

For locomotives,

$$N_{eff} = 3\,[\,7 + 10\,(3)] = 3\,(37) = 111$$

$$L_{dni} = 98 + 10 \log \left(\frac{111 \text{ x } 15}{64}\right) + 10 \log \left(\frac{15}{60}\right)^{1.5} - 25 - 13.8 = 64 \text{ dB}$$

For rail cars,

$$N_{eff} = 60\,[\,7 + 10\,(3)] = 60\,(37) = 2220$$

$$L_{dni} = 76 + 10 \log \left(\frac{2220 \text{ x } 15}{64}\right) + 10 \log \left(\frac{15}{60}\right)^{1.5} - 25 - 13.8 = 55 \text{ dB}$$

Total L_{dn} = 65 dB.

AIRCRAFT FLIGHT OPERATIONS

Comparison With Highway Operations

There are major differences between aircraft and highway operations. With aircraft operations there are multiple, variable paths, as well as numerous types and categories of aircraft. In the vicinity of an airport, we are primarily interested in the noise during takeoff and landing (not the noise of cruising). See Figure 4-8 which depicts the kinds of activities occurring in the vicinity of an airport.

Since we will be concerned with aircraft in the air, noise levels at the observer locations will be based upon air-to-ground sound propagation, rather than ground-to ground sound propagation, with no concern for the impact of shielding elements. Further, there are relatively few noise events, but those that do occur have very high noise levels. 1be pattern of operations is irregular throughout the day and may well vary from day-to-day or month-to-month.

The noise impact from aircraft operations extends perhaps many miles from the source. A final difference relates to the varied frequency spectra among aircraft types and between aircraft and highway vehicles.

Noise Sources

For jet aircraft, the two major sources are the jet exhaust noise and turbo machinery and fan noise (see Figure 4-9). Jet exhaust noise is a roar due to the

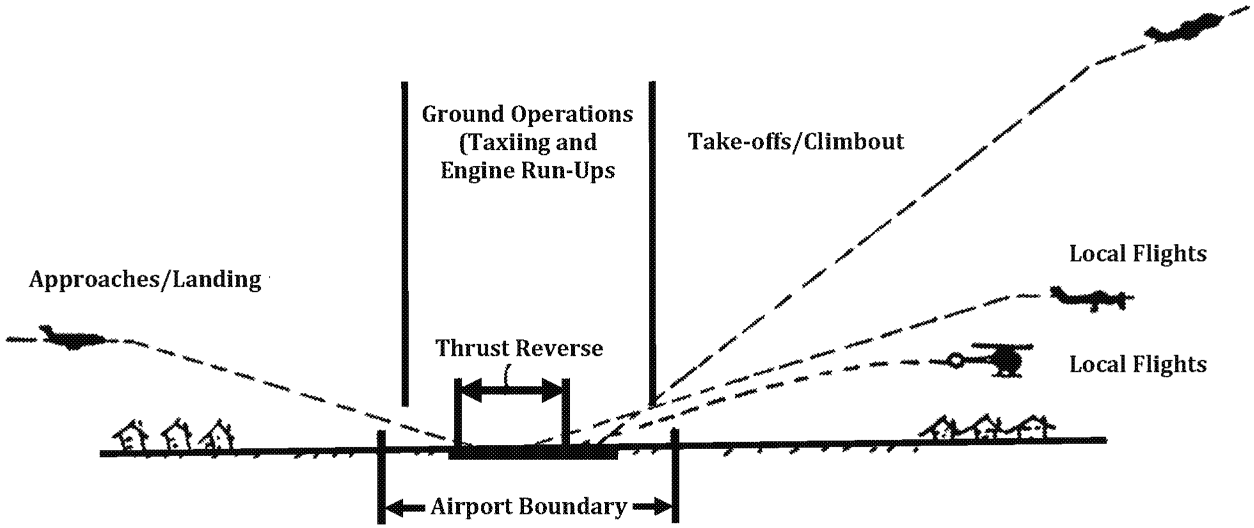


FIGURE 4-8

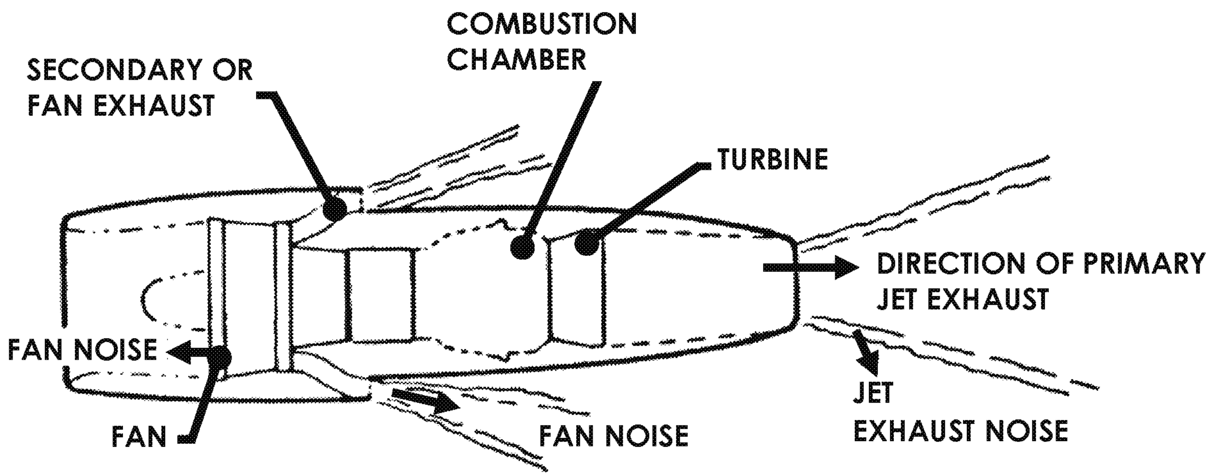


FIGURE 4-9

turbulent mixing of high 'Velocity exhaust gases. It is broad-band in spectrum, with maximum radiation angle of approximately 45° (see Figure 4-10 for a directionality pattern). Because of these directionality characteristics, the maximum noise of a jet aircraft often occurs after the jet aircraft has passed. The noise level will vary with the 6th to 8th power of exhaust velocity. Turbo-machinery and fan noise is also broadband, with strong discrete frequency components, often called pure tones, associated with the blade passage frequency and its harmonics. The blade passage frequency is the number of blades in the compressor or fan multiplied by the rotational frequency.

There are a number of different kinds of jet aircraft engines. In the turbojet engine, the main source of noise is the jet exhaust, with turbomachinery noise becoming important only when jet noise is greatly reduced such as under landing conditions. In the turbofan or bypass fan engine, some intake air bypasses the combustion chamber producing a lower effective exhaust velocity. This reduces the jet exhaust noise, but the intake fan (see Figure 4-9) generates pure tones in the 2000 to 4000 Hz frequency range. Finally, in the high bypass turbofan engine, there is an even higher ratio of intake air which bypasses the combustion chamber. In this engine the effective exhaust velocity is greatly reduced, as is the jet exhaust noise. The inlet guide vanes, fan blades, and outlet vanes of the intake fan are designed to reduce the pure tone level, and shift the tones to less annoying frequencies so that the high bypass turbofan engine, as is found on the newer wide-bodied aircraft such as the B747, L-1011 and DC-10 aircraft, is, for its thrust, relatively quiet.

Propeller aircraft have two major sources of noise, vortex noise and rotational noise. Vortex noise is generated by the formation and shedding of vortices (whirlpools of air) in the flow past the propeller rotor or fan blades. It is broadband in frequency content. Rotational noise consists of pure tones occurring at harmonics of the blade passage frequency. It is generated by the oscillating pressure field on the air due to the passage of the blade. For helicopters, there is also a "blade slap". Fluctuating forces on the blades resulting from cutting one blade's tip vortices by another blade create high amplitude rotational noise plus highly modulated vortex noise. This blade slap has been observed to be quite annoying in the vicinity of helicopter operations.

Aircraft Noise Prediction

In this section we will refer to three techniques for estimating aircraft noise exposure levels. The first technique is to make use of existing noise exposure contours (see Figure

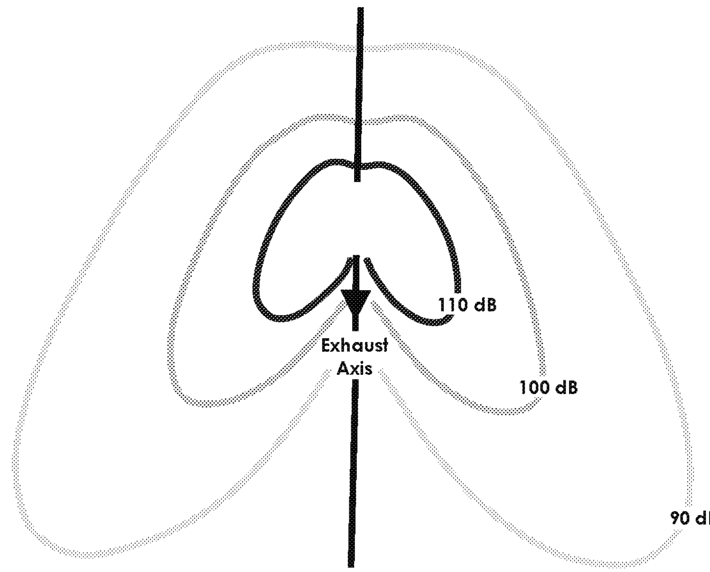


FIGURE 4-10

4-11, for example). For many civil, military, and general aviation airports, noise exposure contours are already available from local government and/or airport authorities. These are often generated as part of an airport master plan, airport expansion or environmental assessment study. If such contours are available, simply locate the site under study on the map and read the noise exposure levels from the contour map.

It is possible to develop approximate contours with a simple set of charts. Since this method is not extremely accurate, it is best used to screen the noise exposure to determine if aircraft impact is significant relative to highway impact. The procedure is as follows:

1. Determine the total number of daytime jet operations, N_d.

2. Determine the total number of nighttime jet operations, N_n.

3. Determine the effective number of operations, $N_{eff} = N_d + 10\ N_n$.

4. Enter the charts in Figure 4-12 to determine distances A and B. These distances are used to draw a lozenge-shaped noise contour for different contour values of L_{dn} as illustrated in the top portion of the figure.

5. Draw the contours of appropriate dimensions around each airport

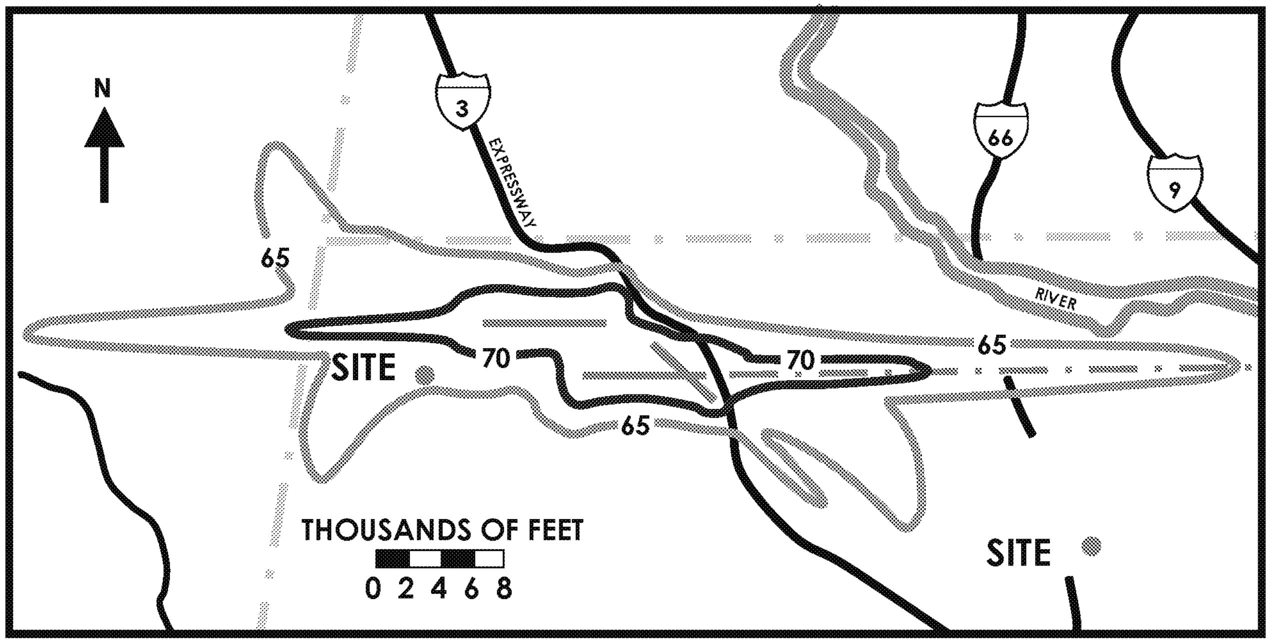


FIGURE 4-11

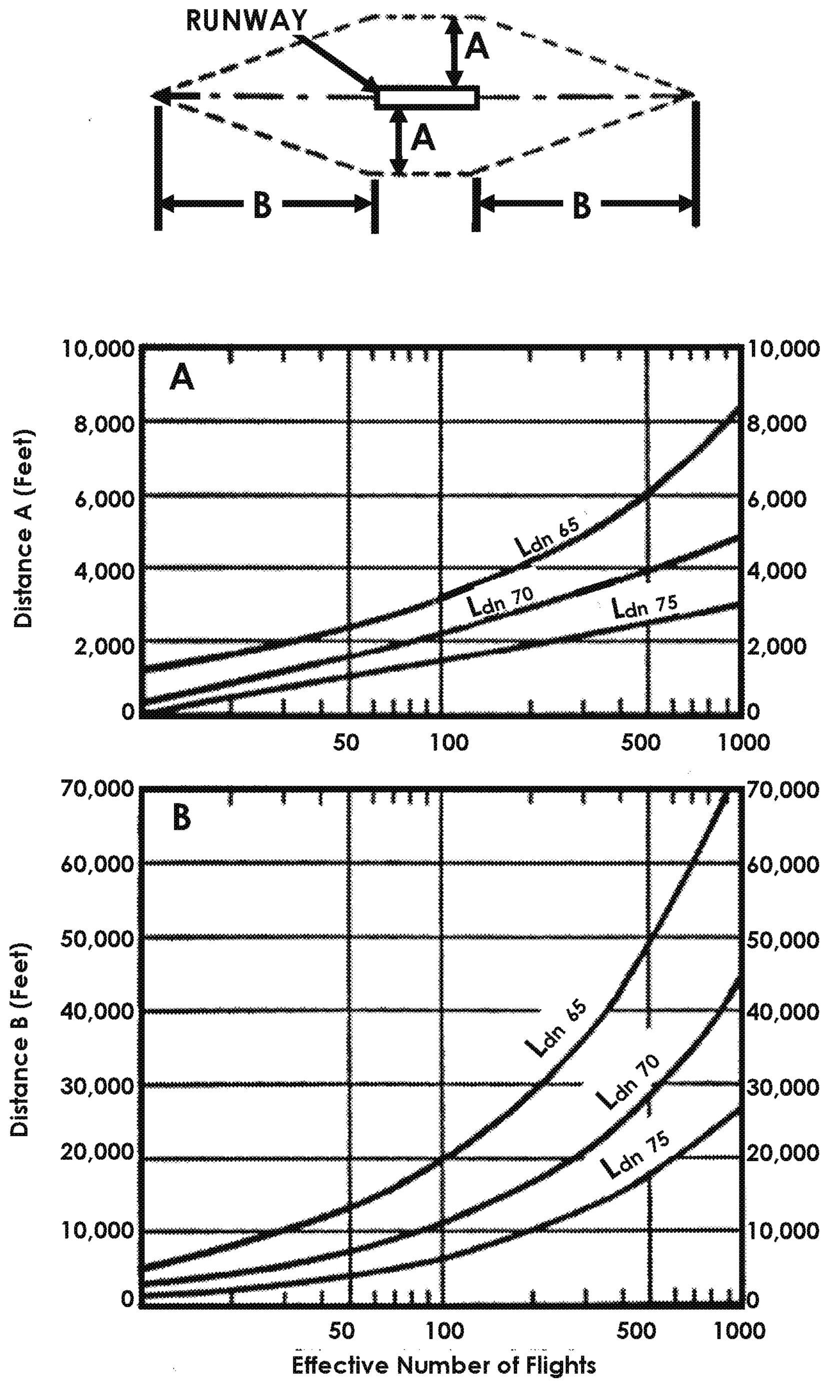

RUNWAY
A
A
B
B
A
Distance A (Feet)
10,000
8,000
6,000
4,000
2,000
0
Ldn 65
Ldn 70
Ldn 75
50
100
500
1000
B
Distance B (Feet)
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Ldn 65
Ldn 70
Ldn 75
50
100
500
1000
Effective Number of Flights

FIGURE 4-12

runway.

6. Locate the area of interest and determine the approximate aircraft L_{dn} value.

7. If aircraft L_{dn} is at least 10 dB below the highway L_{dn}, ignore the aircraft contribution. If the aircraft contribution is not to be ignored determine the aircraft L_{dn} more accurately, as outlined in the procedure to follow.

EXAMPLE:

A site is located near an airport with two runways. There are 125 daytime and 10 nighttime jet operations. Draw approximate contours and determine if the L_{dn} at the site is at or above 65 dB.

For these operations, N_{eff} = 125 + 10 (10) = 225. From the charts A = 2000 and 4200 ft for the 65 and 75 dB contours, and B = 11,000 and 31,000 ft for the same contours. The resulting contours are shown in Figure 4-13; the site L_{dn} is well below 65 dB.

The more accurate prediction of aircraft Lan values is adopted from an EPA handbook "Calculation of Day-Night Levels (L_{dn}) Resulting from . Civil Aircraft Operations" (EPA Report 550/9-77-450). The procedure outlined in this handbook permits the prediction of the day-night level at a single point, rather than the develop-

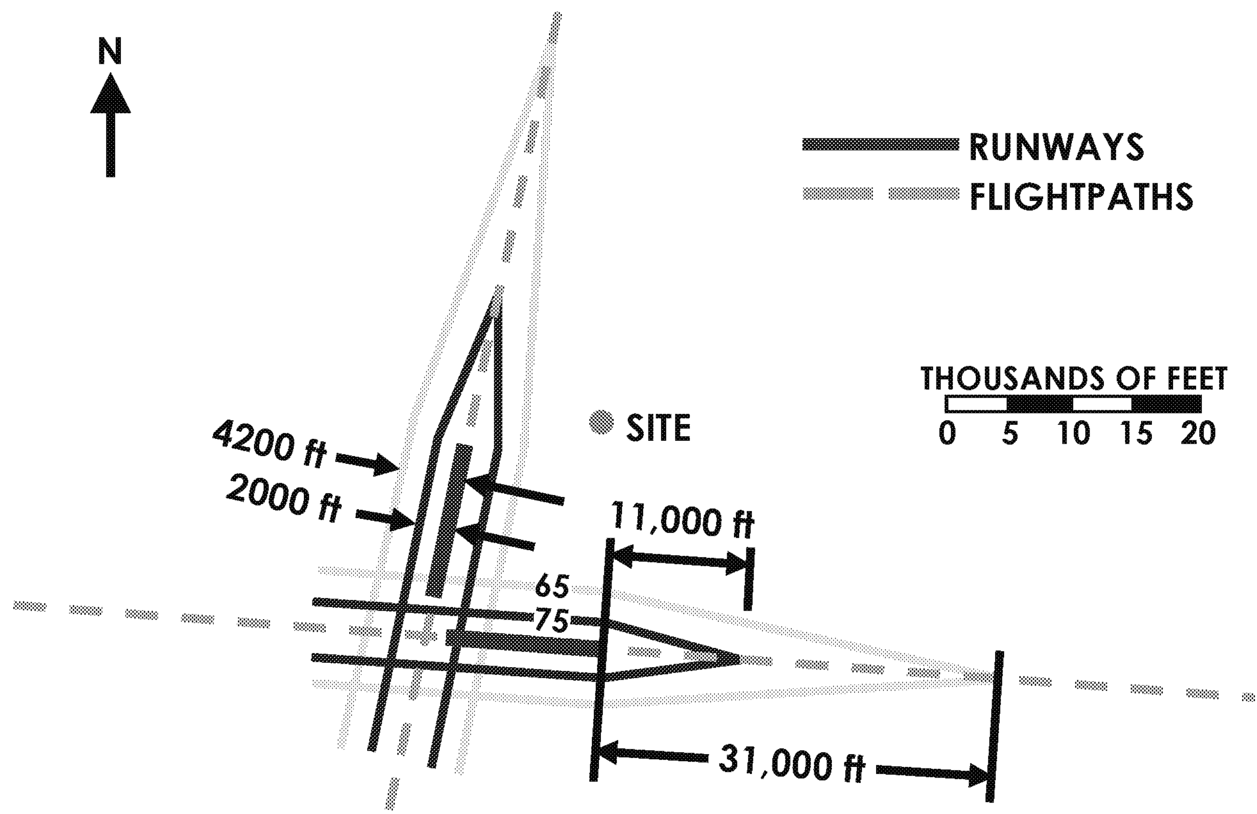


FIGURE 4-13

ment of actual noise contours. In this method, aircraft noise is categorized by type of aircraft and type of operation. The noise exposure contribution of each aircraft operation is described by its sound exposure level, SEL. For each type of aircraft operation, i, the Lan is determined according to the equation:

$$L_{dni} = SEL_i + 10 \log (N_{di} + 10\, N_{ni}) - 49.4$$

The total L_{dn} is then just the decibel sum of the L_{dni}'s of contributing aircraft types. Steps in the procedure are as follows:

1. Gather field information. Determine the physical layout and length of runways, and location of major flight tracks relative to the observer position. Figures 4-14 and 4-15 define two important parameters, D_1 and D_2 for both takeoff and approach operations.

   These distances will be used below in the determination of SEL values. Determine the various types of aircraft and their operational characteristics, and the number of daytime and nighttime operations for each aircraft type. Determine flight path utilizations and whether any special procedures exist.

2. Determine the SEL for each contributing aircraft event. The handbook contains a series of noise charts, such as the example shown in Figure 4-16. The charts are

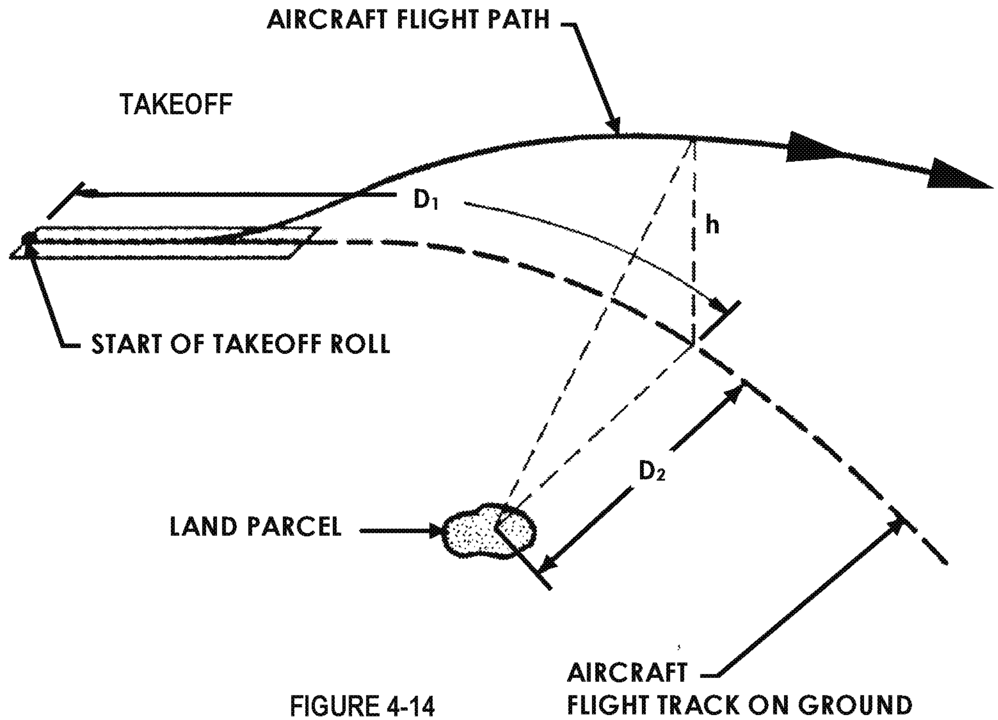


FIGURE 4-14

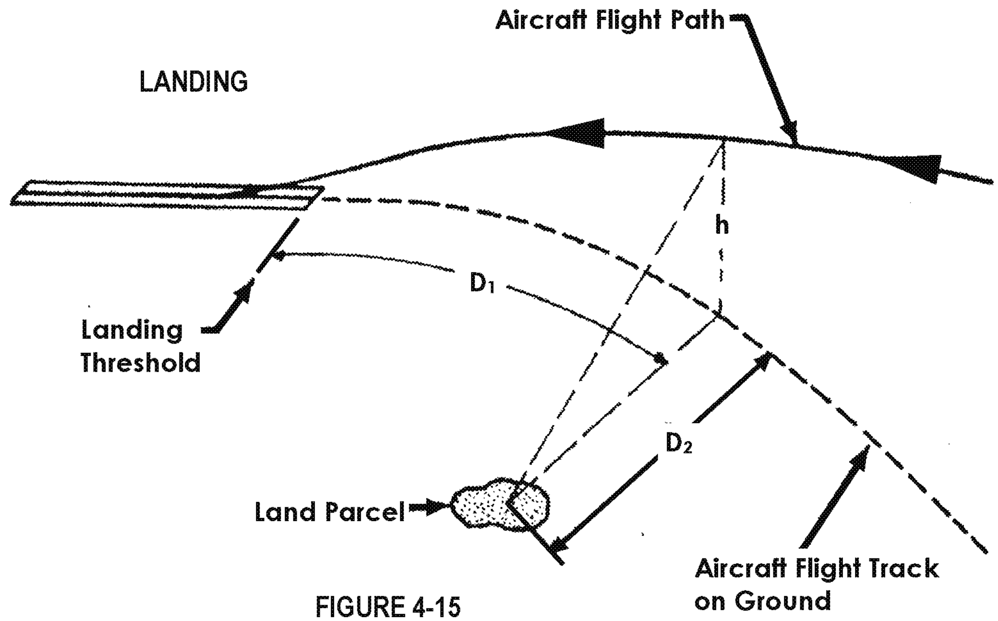
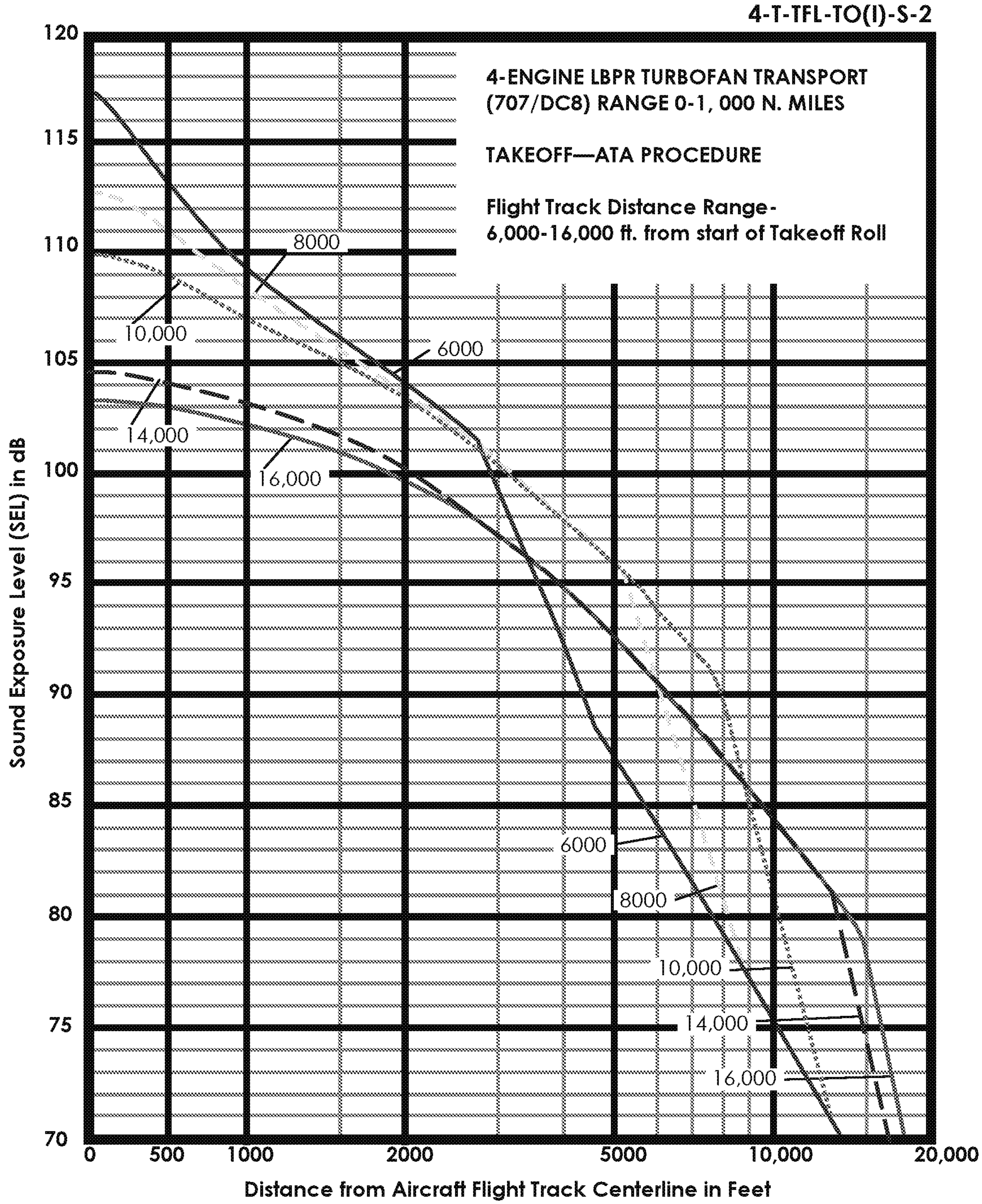


FIGURE 4-15



4-T-TFL-TO(I)-S-2
4-ENGINE LBPR TURBOFAN TRANSPORT
(707/DC8) RANGE 0-1, 000 N. MILES
TAKEOFF—ATA PROCEDURE
Flight Track Distance Range-
6,000-16,000 ft. from start of Takeoff Roll
Sound Exposure Level (SEL) in dB
120
115
110
105
100
95
90
85
80
75
70
8000
10,000
6000
14,000
16,000
6000
8000
10,000
14,000
16,000
0
500
1000
2000
5000
10,000
20,000
Distance from Aircraft Flight Track Centerline in Feet

FIGURE 4-16

identified by a 6 component code, based on number of engines, type of aircraft, type of operation, and type of engines (see the handbook for more details). Select the noise chart corresponding to the aircraft event in the vicinity of the observer location. With the appropriate values of D_1 and D_2, read the SEL from the chart.

3. Compute the partial day-night level. For each category of aircraft event, determine the value of K from the chart shown in Figure 4-17 using N_d and N_n. The chart depicts graphically the equation $K = 49.4 - 10 \log (N_d + 10 N_n)$. The partial L_{dn} is simply the sound exposure level value minus K for each category of aircraft.

4. Add the partial L_{dn} values together to obtain the total L_{dn} for all operations.

A worksheet, shown in Figure 4-18, is included in the handbook to facilitate the tabulation of operational information, noise data, and the final calculations. Also, Figure 4-19 lists noise levels by aircraft type at a single location, to give the reader a feeling for the relative noisiness of individual types of aircraft.

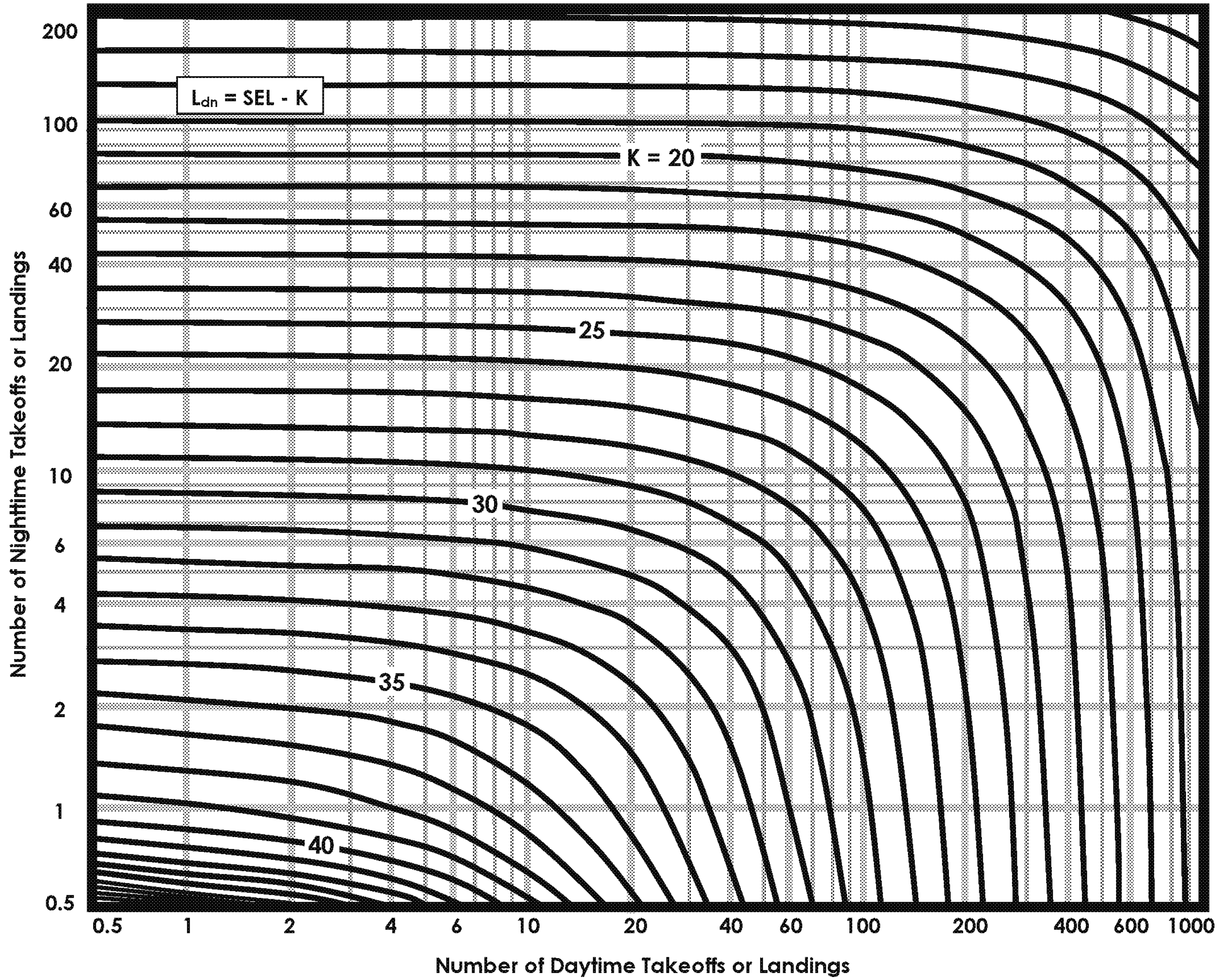


FIGURE 4-17

EXAMPLE:

A particular runway is used exclusively by 4-engine LBPR turbofan aircraft (eg. 707's). There are 30 daily takeoffs, including 3 at night. Estimate the L_{dn} at a location 800 feet to the side of the flight track, at a point 18,000 feet from start of takeoff roll.

At this location D_1 = 18,000 and D_2 = 800. From the chart, the SEL for these parameters is 103 dB. For 27 daytime takeoffs and 3 nighttime takeoffs K = 32. Then L_{dn} = l03 - 32 = 71 dB.

Other Aircraft Noise Descriptors

Although the day-night level is the noise descriptor utilized in this document, there are two other descriptors of which the reader should be aware.

The first of these is the Community Noise Equivalent Level, or CNEL. This measure is used exclusively in California. The CNEL is similar to the day-night level, except that an adjustment of 5 dB is utilized for evening hours (7 p.m. to 10 p.m.) in addition to the nighttime adjustment of 10 dB. Otherwise, the CNEL is identical to the day-night level, and for most situations, CNEL equals L_{dn}. The second measure to be aware of is the noise exposure forecast, or NEF. NEF values are based on summation of effective perceived noise level, or EPNL, values instead of SEL

AIRPORT ____________ FLIGHT TRACK ☐ MAP ☐ OTHER

TRACK					
AIRCRAFT					
OPERATION					
N_D					
N_N					
D_1					
D_2					
CHART					
SEL					
K					
PARTIAL L_{DN}					

TOTAL L_{DN} ____________

FIGURE 4-18

values. EPNL values differ from SEL values in that the perceived noise level weighting instead of the A-weighting is used in the measure (this weighting puts somewhat more emphasis on the low-frequency portion of the spectrum), and the EPNL incorporates a "pure tone" penalty in the measure. Also, the NEF incorporates a nighttime weighting factor of 16.67 instead of 10. The noise exposure forecast was developed earlier than the day-night level, but is still used in some parts of the country and by some agencies, even though most agencies have shifted over to the day-night level descriptor. To a first approximation, Lan equals NEF plus 35 dB.

SUMMATION OF SOURCES

Thus far, prediction procedures have been described to permit the estimation of the day-night level for generalized background noise, railroad line operations, and civil aircraft operations. In order to combine these with the noise of highway operations, the day-night level due to highway operations must be determined as well. If we assume that the peak hour equivalent sound level has already been determined at the point of interest for the highway, the steps to determine the day-night sound level are as follows:

1. Determine the peak hour percentage of the 24-hour volume.

NOISE CHART CODES ASSOCIATED WITH AIRCRAFT TYPES

RANKED BY APPROXIMATE NOISINESS

Aircraft Type	Aircraft Code	Typical Aircraft	Takeoff SEL at 15,000 ft. from Start of TO[1], dB	Landing SEL at 6,000 ft. from Threshold[2], dB
4-Engine HBPR turbofan	4-T-TFH	747	111.5	108.3
4-Engine LBPR turbofan	4-T-TFL	707, DC-8	110.9	106.4
4-Engine LBPR turbofan (quiet nacelle)	4-T-TFL(Q)	707 (QN) DC-8 (QN)	109.7	97.2
3-Engine LBPR turbofan	3-T-TFL	727	109.6	101.1
3-Engine LBPR turbofan (quiet nacelle)	3-T-TFL(Q)	727 (QN)	109.3	96.1
4-Engine HBPR turbofan (quiet nacelle)	4-T-TFH(Q)	727 (QN)	108.6	103.1
2-Engine Composite Business Jet (turbojet/turbofan)	2-G-TJ	Jetstar I, Learjet 23-25, Learjet 35-36, Jetstar II	104.9	101.3
2-Engine LBPR turbofan	2-T-TFL	737, DC-9	101.9	94.3
2-Engine LBPR turbofan	2-T-TFL(Q)	737 (QN), DC-9 (QN)	101.9	93.1
3-Engine HBPR turbofan	3-T-TFH	L-1011, DC-10	101.8	98.8
4-Engine propeller	4-T-TP	DC-4, DC-6	98.8	90.3
4-Engine turboprop	4-T-TP	Electra	97.8	92.1
2-Engine G.A.[3] turboprop	2-G-TP	Twin Otter, King Air, Turbo Commander	93.5	92.4
2-Engine G.A.[3] propeller (large)	2-G-LPP	DC-3	92.5	87.3
2-Engine G.A.[3] propeller (small)	2-G-SPP	Cessna 310-401	83.2	80.5
2-Engine G.A.[3] turbofan (small)	2-G-TFS	Cessna Citation	81.4	80.3
1-Engine G.A.[3] propeller	1-G-PP	Cessna 150-210, Piper Cher. 140-235	81.8	72.9

[1] ATA (Air Transport Association) takeoff procedure at max. weight category

[2] 3° approach

[3] General aviation

FIGURE 4-19

2. Determine the daytime and nighttime percentages of the 24-hour volume.

3. Use the charts in Figure 4-20 to obtain adjustments Δ1 and Δ2.

4. The day-night level is then the summation of the peak hour L_{eq} with Δ1 and Δ2.

This approximation for the day-night level incorporates certain assumptions. It is assumed that the speed of highway vehicles remains relatively unchanged throughout most of the day. It also assumes that the volume percentages used in the charts in Figure 4-20 are appropriate to both automobiles and heavy trucks. It should be pointed out that the method is relatively insensitive to these assumptions, however, since it has been found for many roadways studied that the L_{dn} is equal to the peak hour L_{eq} ± 2 dB. This makes sense if one looks at the charts for typical traffic flows in which the peak hour percentage ranges from 8 to 12 percent and the nighttime percentage of the ADT ranges from 10 to 20 percent.

The total day-night level at each observer point is then the decibel sum of the contributing L_{dn}'s due to highway, rail, and aircraft sources, and the general background community noise.

EXAMPLE:

A site is exposed to L_{dn} values of 58 dB from aircraft overflights and 62 dB from a nearby railroad track. Also, the peak hour L_{eq} from a highway in the area is 65 dB. For this highway, the peak hour traffic is 8% of the ADT, and daytime traffic accounts for 80% of the ADT. Determine the total L_{dn} for the site, if it is located in an area with a population density of 5000 people per square mile.

For $\rho = 5000$, $L_{dn} = 10 \log (5000) + 22 = 59$ dB

For the highway, $\Delta 1 = -2.8$;

$\Delta 2 = 4.5$.

$L_{dn} = 65 - 2.8 + 4.5 = 67$

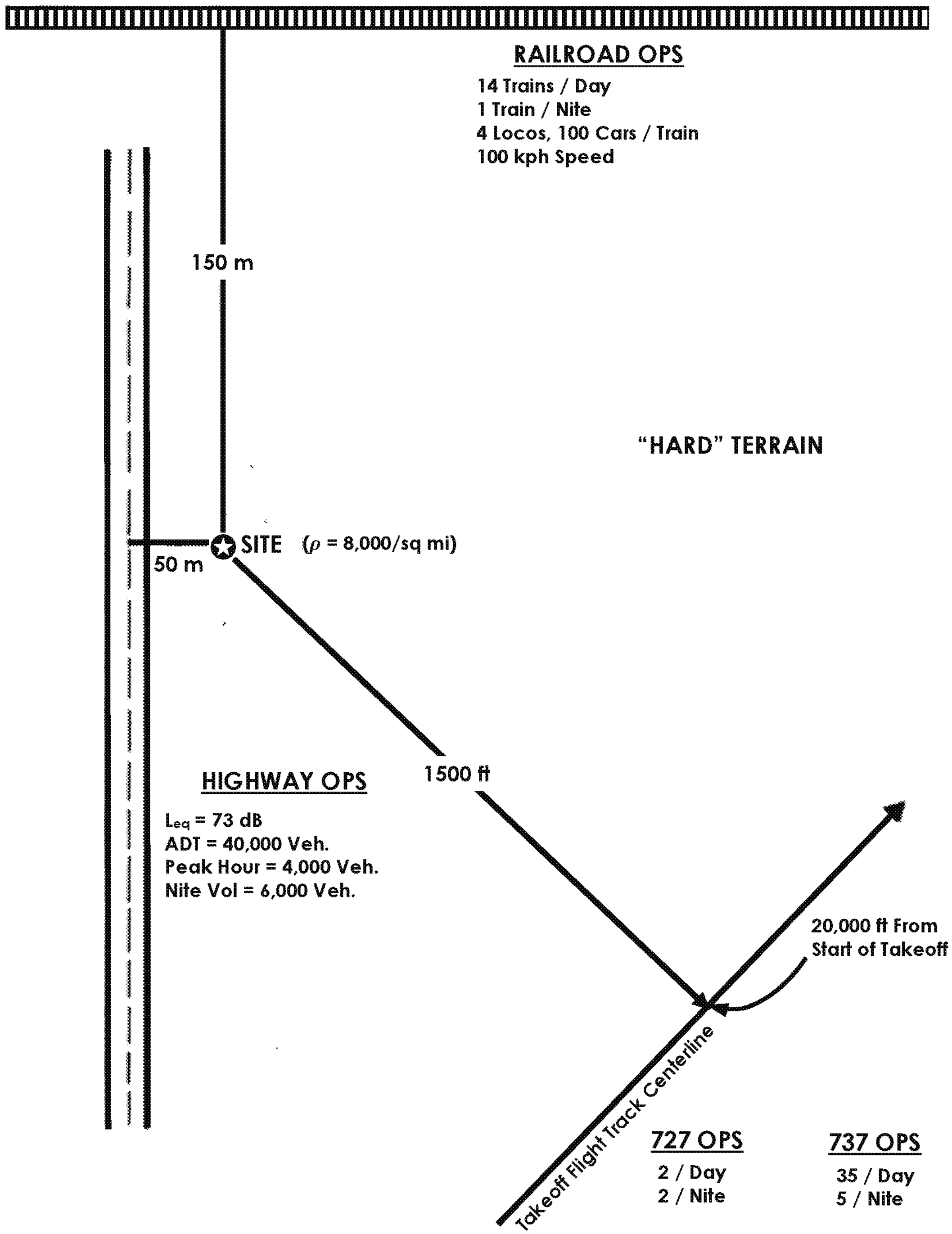
The total L_{dn} is the sum of 58 (aircraft), 62 (railroad), 67 (highway) and 59 (background), or 69 dB.

A complete example for the student to try is depicted on the next page. First, compute the L_{dn} due to the highway alone, due to all other sources, and due to all sources. Then examine the benefit of barriers which reduce highway noise only, by 5, 7, 10 and then 15 dB. How effective are these barriers? (SEL data for aircraft are attached.)

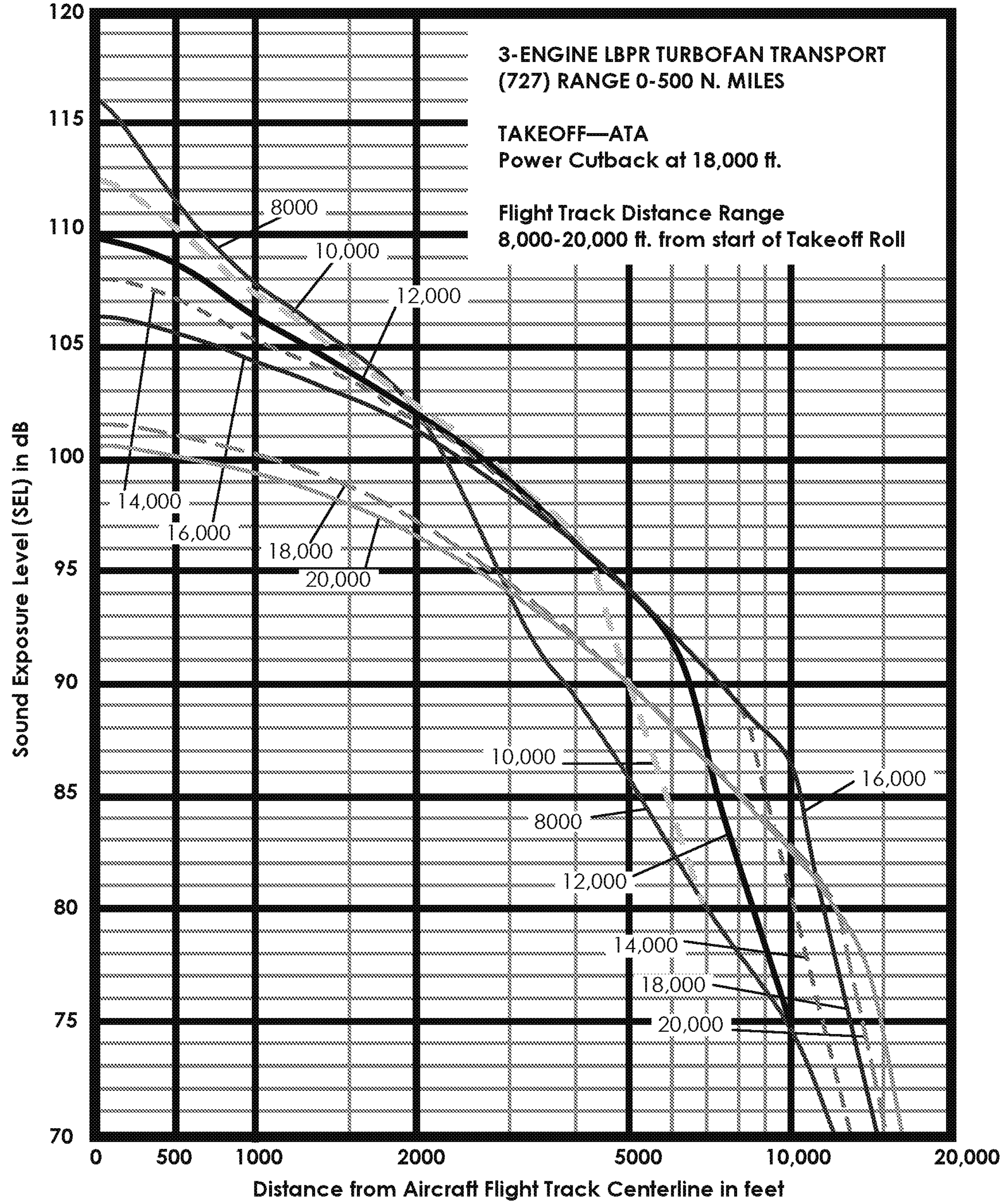
Peak Hour % of ADT	**Δ_1, dB**
4	0.2
5	-0.8
6	-1.6
7	-2.3
8	-2.8
9	-3.3
10	-3.8
11	-4.2
12	-4.6
13	-4.9
14	-5.3
15	-5.6
17	-6.1
20	-6.8

Day % of ADT	**Nite % of ADT**	**Δ_2, dB**
100	0	0
95	5	1.6
90	10	2.8
85	15	3.7
80	20	4.5
75	25	5.1
70	30	5.7
65	35	6.2
60	40	6.6

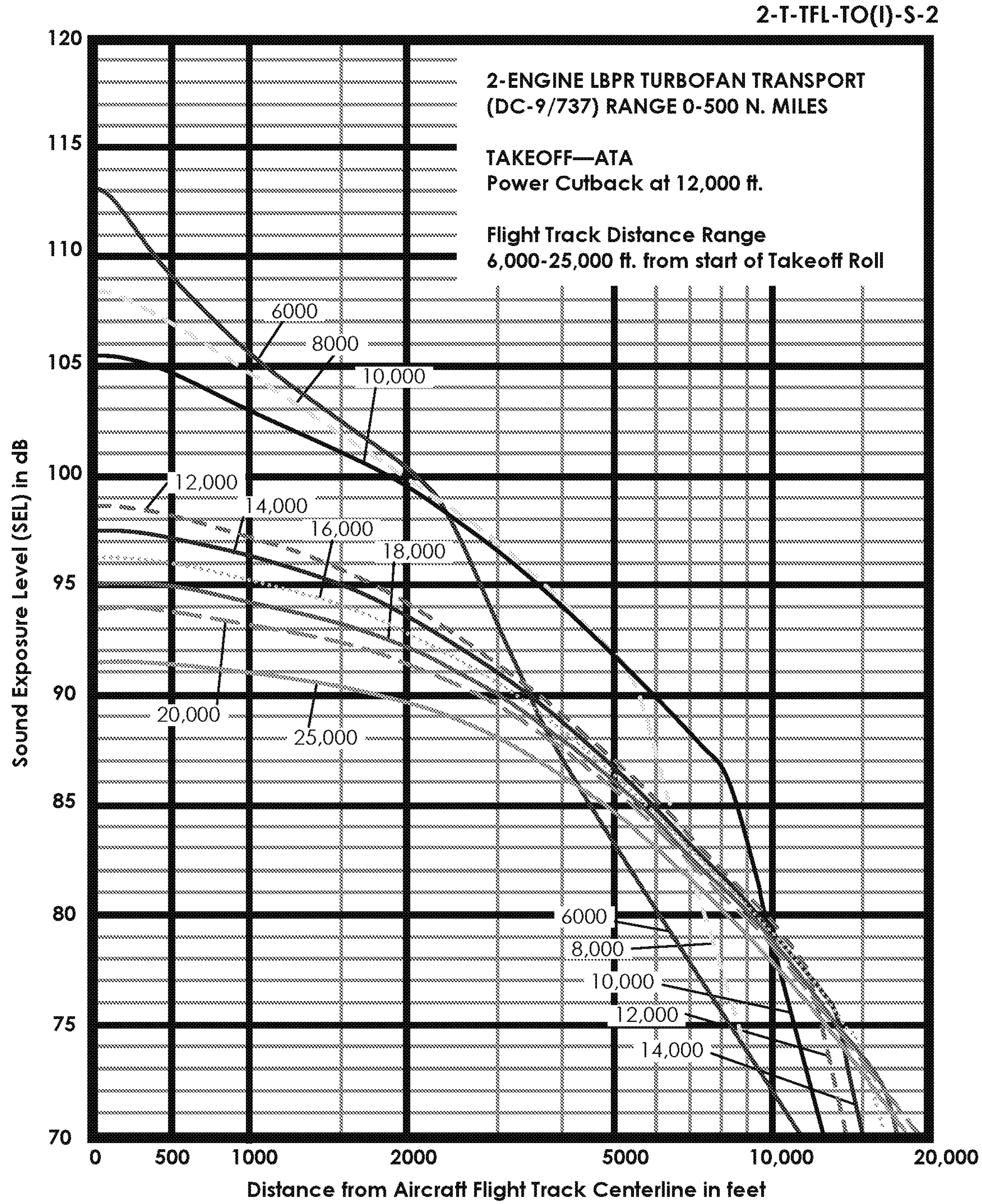
FIGURE 4-20


RAILROAD OPS
14 Trains / Day
1 Train / Nite
4 Locos, 100 Cars / Train
100 kph Speed
150 m
"HARD" TERRAIN
SITE (ρ = 8,000/sq mi)
50 m
1500 ft
HIGHWAY OPS
L_{eq} = 73 dB
ADT = 40,000 Veh.
Peak Hour = 4,000 Veh.
Nite Vol = 6,000 Veh.
20,000 ft From Start of Takeoff
Takeoff Flight Track Centerline
727 OPS
2 / Day
2 / Nite
737 OPS
35 / Day
5 / Nite

3-T-TFL-TO(I)-S-2



3-ENGINE LBPR TURBOFAN TRANSPORT
(727) RANGE 0-500 N. MILES
TAKEOFF—ATA
Power Cutback at 18,000 ft.
Flight Track Distance Range
8,000-20,000 ft. from start of Takeoff Roll
Sound Exposure Level (SEL) in dB
120
115
110
105
100
95
90
85
80
75
70
0
500
1000
2000
5000
10,000
20,000
Distance from Aircraft Flight Track Centerline in feet
8000
10,000
12,000
14,000
16,000
18,000
20,000
10,000
8000
12,000
16,000
14,000
18,000
20,000



2-T-TFL-TO(I)-S-2
2-ENGINE LBPR TURBOFAN TRANSPORT
(DC-9/737) RANGE 0-500 N. MILES
TAKEOFF—ATA
Power Cutback at 12,000 ft.
Flight Track Distance Range
6,000-25,000 ft. from start of Takeoff Roll
Sound Exposure Level (SEL) in dB
Distance from Aircraft Flight Track Centerline in feet
120
115
110
105
100
95
90
85
80
75
70
0
500
1000
2000
5000
10,000
20,000
6000
8000
10,000
12,000
14,000
16,000
18,000
20,000
25,000
6000
8,000
10,000
12,000
14,000

SOLUTION TO THE EXAMPLE

1. L_{dn} (Background) = 10 log (8000) + 22 = 61

2. L_{dn} (RR):

Locos: $L_{dn} = 98 + 10 \log \frac{24 \cdot 4 \cdot 15}{100} + 10 \log \frac{15}{150} - 25 - 13.8$

Rail Cars: $L_{dn} = 82 + 10 \log \frac{100 \cdot 24 \cdot 15}{100} + 10 \log \frac{15}{150} - 25 - 13.8$

$L_{dn} = 60.8 + 58.8 \approx 63$ dB

3. L_{dn} (A/C):

727 : SEL = 98, K = 36, L_{dn} = 62

737 : SEL = 92, K = 30, L_{dn} = 62

Total A/C L_{dn} = 62 + 62 = 65 dB

4. L_{dn} (H/W): 73 + (-3.8) + 3.7 ≈ 73

5. Effect of Noise Barrier:

		Highway Barrier NR			
	No Barrier	5 dB	7 dB	10 dB	15 dB
Highway L_{dn}	73	68	66	63	58
Other L_{dn}	68	68	68	68	68
Total L_{dn}	74	71	70	69	68