

LOCATION-DESIGN NOISE CONTROL OF TRANSPORTATION SYSTEMS

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ABSTRACT

The annoyance problem caused by the radiation of transportation system noises into nearby inhabited areas is acknowledged, and schemes for controlling such noises are discussed. Site selection for transportation facilities emphasizing compatible land use in bordering areas, erection of barriers, use of cuts, and design changes and acoustical treatment of certain kinds of transportation installations are shown to be effective noise abatement measures.

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SUMMARY

Noise conditions found around different transportation facilities including airports, roadways, and rail lines are described together with procedures for rating the complaint potential for this noise in impacted inhabited areas. The merits of various location and design measures for reducing problems of undue noise radiation from transportation installations are appraised. Site selection for these installations compatible with surrounding land use is acknowledged as a key noise control measure. Depending on height and distance, erection of barriers between the transportation facility and the nearest receiver are also shown to provide significant sound attenuation as does locating the installation in a cut or depression. Unless broad regions are available for planting, the use of trees and shrubs will not constitute an effective sound barrier. Design modifications for vibration isolation, for elimination of irregularities in vehicle contact surfaces, and the use of sound absorbent materials in certain transportation facilities are found to cause some reduction in the amount of radiated noise. Final comment is given to the problem of sonic-booms expected with the advent of commercial super-sonic air service.

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INTRODUCTION

That there is increasing awareness of noise problems in transportation systems can be illustrated in various ways. Airline maintenance crews and select airport personnel now wear ear protectors when servicing aircraft so as to minimize the risk of noise-induced hearing loss. The flyover noise of jet aircraft has caused widespread complaints in residential areas near airports prompting organized community action to curtail, if not halt, the activities of the noise-maker (1, 2, 3). As a result, operational noise ceilings are now in effect at major airports in this country and Congress is considering bills which would establish a Federal commission concerned with aircraft noise abatement (4, 5). Several States and cities have enacted or are in process of adopting laws which will specify maximum permissible noise levels for automobiles, trucks, buses and motorcycles operating on State or local roads (cited in Reference 6). This is in response to the growing noise-annoyance problems caused by increasing traffic along city streets and expressways. In another vein, one automobile manufacturer has advertised that his product's interior is quieter than that of a much more expensive and prestigious car. An airline has dubbed its fleet of aircraft "whisper-jets" to depict the acoustic comfort experienced by its passengers in flight. (I might add here that the airport neighbors who hear the noise of such aircraft overhead would probably be inclined to offer another name!!)

Efforts to control transportation noise have had only limited success, and the proposed development of faster, more powerful vehicles with greater load-carrying abilities raises the specter of more severe vehicle noise problems in the future. This paper is intended to describe various design and location schemes for reducing noise in transportation systems. Techniques for quieting vehicle engines, probably the best means for correcting this problem, will not be discussed since they are not believed appropriate for this audience. Rather, concern here will be given to those measures which take account of the transportation facilities used by the operating vehicles, (i.e., the airport and rail installations, roadways and tunnels). These corrective treatments will be assessed in terms of their ability to reduce the air-borne and structure-borne noise being generated or

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transmitted by a transportation system into a neighboring area. More specifically, this evaluation will take the form of determining the extent to which a given noise control procedure will provide levels of transportation noise acceptable to the roadside or railside dweller, to the airport neighbor. Obviously, such noise reduction could also benefit vehicle operators, passengers and the work crews servicing the system. Noise control requirements for these latter groups, however, may be different from those applied to people living in the vicinity of the transportation facility. As noted in the illustrations given at the outset of this paper, transportation workers require a work environment where noise conditions potentially hazardous to their hearing must be controlled; the neighbors of a transportation system demand far quieter conditions, accepting only those noise levels that pose no hindrance to their privacy, comfort and well-being.

DESCRIPTION AND EVALUATION OF TRANSPORTATION NOISE PROBLEMS

The solution of a noise problem usually begins by describing the characteristics of the noise source or noise field and ascertaining the basis for the noise being generated. Physical description of noise includes over-all sound pressure level (SPL) measurements, reflecting the average energy contained in the noise for a broad range of audible frequencies, usually 20-10,000 cycles per second (cps), and spectrum determinations which show how the noise energy is distributed among the frequencies comprising this range. The latter spectrum data are obtained by dividing the total range of frequencies into frequency bands, usually an octave or one-third octave in width, and measuring the sound pressure level in each band. All sound pressure level measurements are expressed in decibels (dB) in accordance with the formula:

$$NdB = 20 \log_{10} \frac{P_1}{P_0}$$

where NdB = number of decibels

P_1 = root-mean-square average of the pressure changes underlying sound being measured.

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P_0 = reference root-mean-square pressure change, usually 0.0002 microbar, corresponding to weakest audible sound.

Figure 1 shows typical over-all octave-band SPL readings in dB for a variety of transportation noise sources as measured under specified conditions. Also noted for comparison purposes are the over-all noise levels found in different industrial and community environments. The over-all levels observed for the transportation noise vary from 79 to 101 dB, the lower value being equal to that found in large offices with tabulating machines, the upper value being similar to that found in plant areas where weaving or metal shaping operations are going on. Note that all of the observed transportation noise levels exceed those indicated for a typical quiet residential street or one where there was some background noise from distant traffic and industry.

While these comparisons are suggestive, over-all noise levels are seldom used in making judgments about noise problems since they can be misleading. For example, Figure 1 shows the jet and propeller aircraft flyover noise to have the same over-all levels which might suggest that they also cause the same intrusive effects and require similar noise control treatment. In actuality, however, the jet noise creates a greater annoyance effect because its spectrum shows relatively more energy in the high frequency octave-bands. People are less tolerant of intruding noise, especially if it has strong high frequency energy and, consequently, is high pitched in nature (7). On the other hand, sound reduction techniques suppress high frequency sounds more effectively than low frequencies (8). Hence, the less annoying propeller aircraft noise would raise more formidable noise control problems should such sounds require significant suppression.

Weighted over-all noise level measurements taken on the A-scale network of a conventional sound-level meter have been used to gauge the nuisance value of a given noise (9, 10). A-scale readings in decibels, abbreviated dBA, selectively discriminate against low

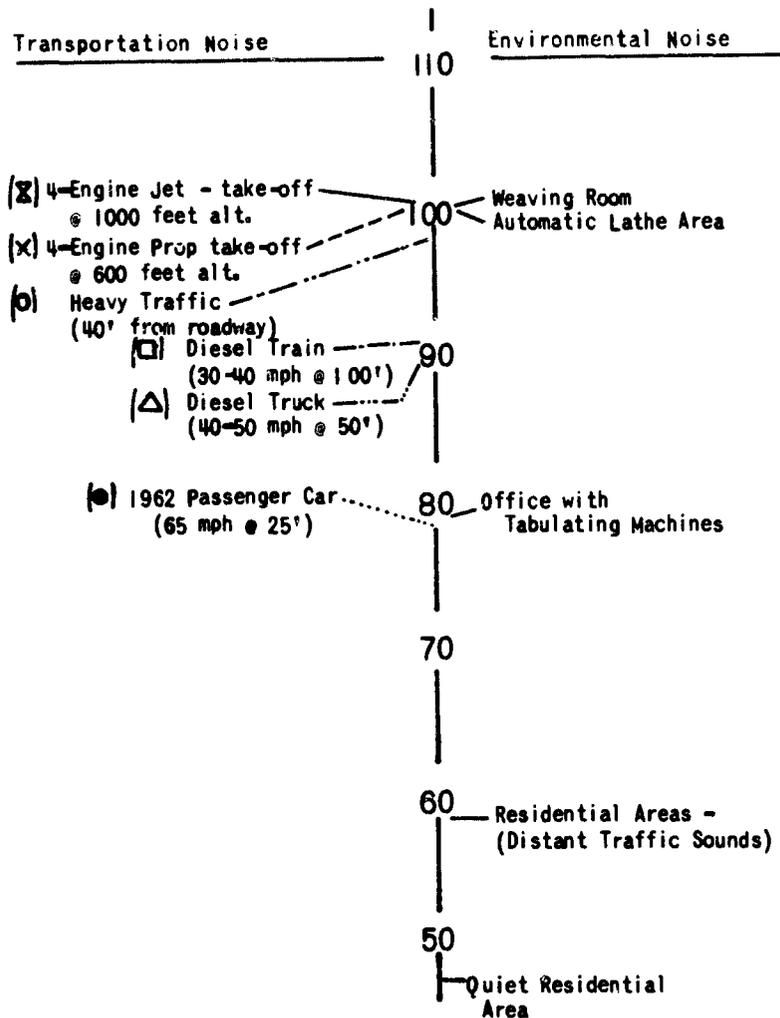
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frequency, and to a lesser extent, high frequency energy in a manner which conforms to the variation in loudness sensation produced by different frequency sounds of moderate intensity. Figure 2 compares the unweighted over-all readings of the traffic noise previously shown in the first figure with equivalent A-scale readings. The relative order and magnitudes of the A-scale values differ from the unweighted measures for the same set of noises. A-scale values do bear some correspondence to listeners' objectionability ratings especially for limited classes of noises (e.g., motor vehicle noises (9, 10)).

A-scale determinations, however, are not as useful as octave- or one-third octave band spectrum data in noise control work where effective treatment depends on locating the specific frequency region(s) contributing the most energy to the noise. The spectrum data can also serve as a basis for computing various subjective measures of noise which more closely match listeners' annoyance judgments of noise than do the A-scale values (11). One such measure is called perceived noise level in dB, measured in units of PNdB (12). The perceived noise level of a noise is obtained from a series of calculations which essentially weight the octave- or one-third octave-band levels of the noise in accordance with functions describing equal annoyance judgments for different frequency sounds set at various intensities.

PNdB values can facilitate the evaluation of the acceptability of different noise conditions in various ways. For example, given two noises with different spectra, one could predict from spectral conversions to PNdB which of the two would be perceived as noisier, thus less acceptable. Given a noise control treatment providing specified amounts of sound attenuation at various frequencies, one could predict how much reduction in noisiness would occur in applying this treatment to a known noisy condition by comparing the PNdB values computed for the unattenuated and expected attenuated states of the noise. Figure 3 shows typical PNdB levels for vehicle noises heard at various distances as reported by Kryter (13). The shaded boxes on each curve indicate the estimated PNdB levels at dwellings typically nearest the specified noise source. Sound jury tests have found noises of 100 PNdB to be rated as "barely acceptable" (13). According to Figure 3, this would be equal to the noise heard from trucks or motorcycles at 50 feet, from diesel trains at 200 feet, and from propeller aircraft at 500 feet altitude. Reflecting their unacceptability, the noise from jet aircraft operations is higher than this 100 PNdB level as heard at houses nearest the noise source. To be more meaningful, however, these PNdB evaluations, or

OVERALL SOUND LEVEL IN dB



OCTAVE-BAND SPECTRA - TRANSPORTATION NOISE

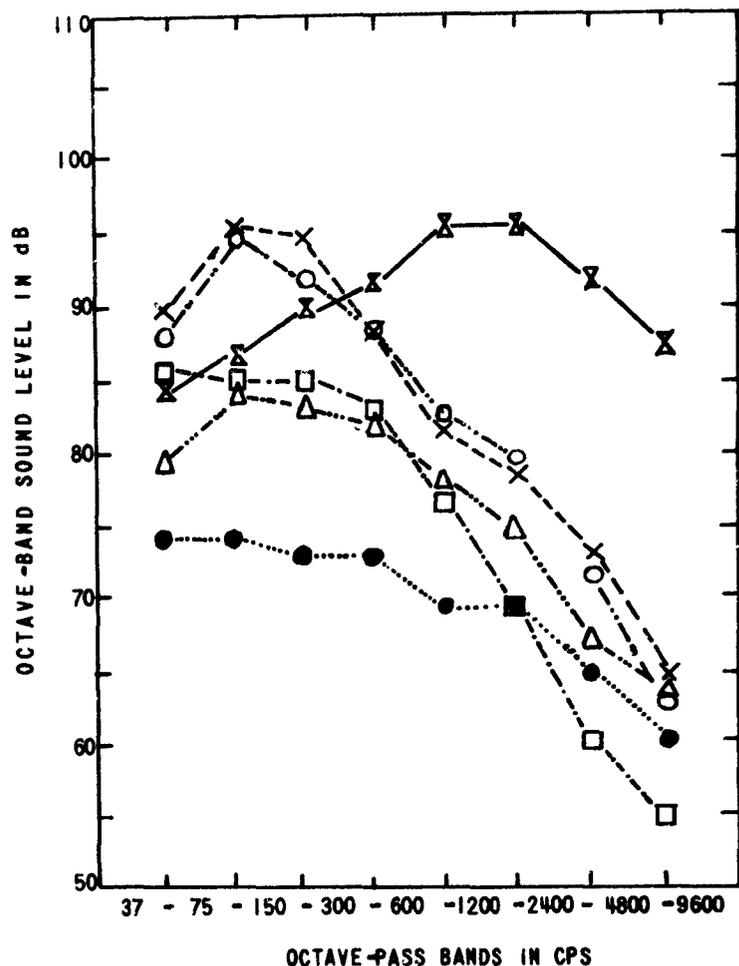


Figure 1. Over-all and octave-band sound pressure levels in dB (re 0.002 microbar) for variety of transportation noises as measured under the conditions specified. Also shown are over-all noise levels in industrial and community environments.

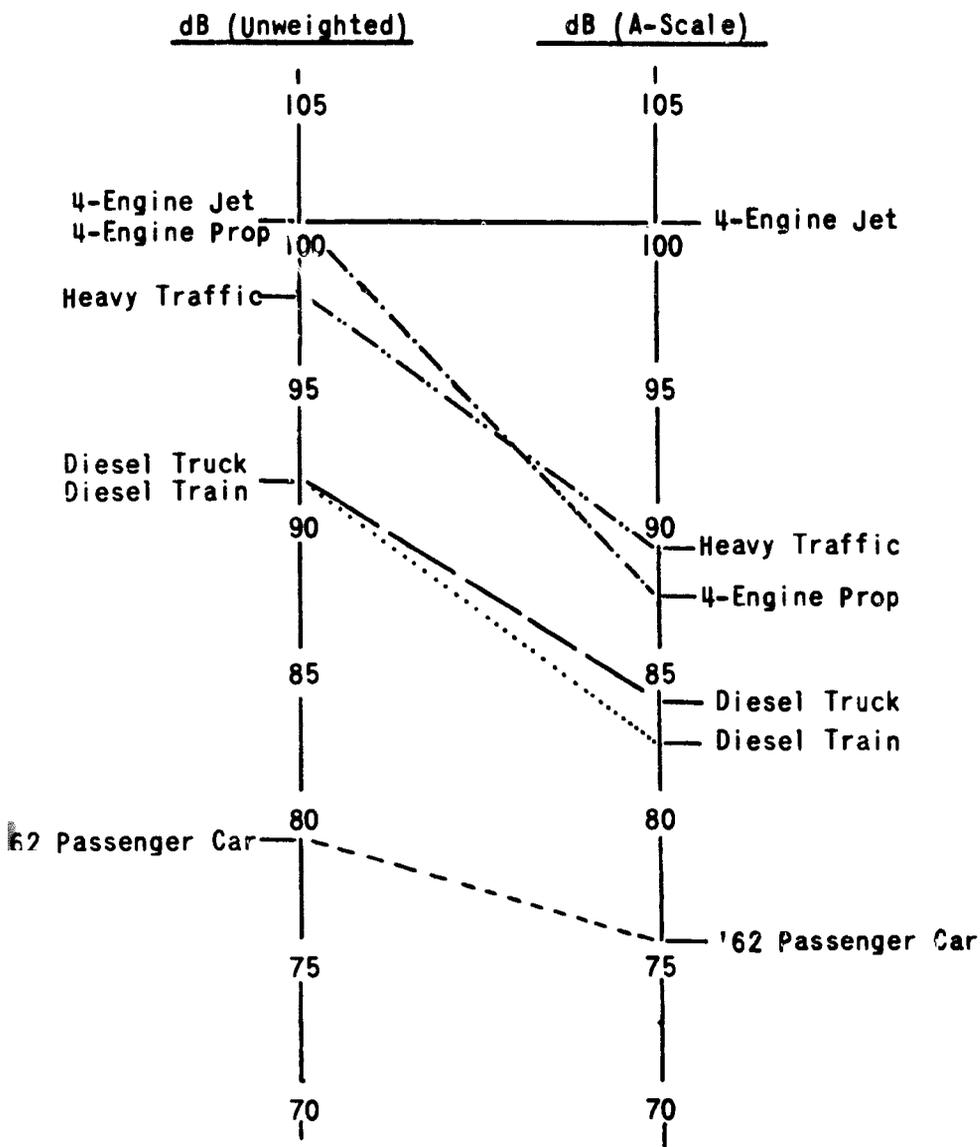


Figure 2. Comparison of unweighted (C-scale) over-all noise level readings for various transportation noises with equivalent A-scale readings.

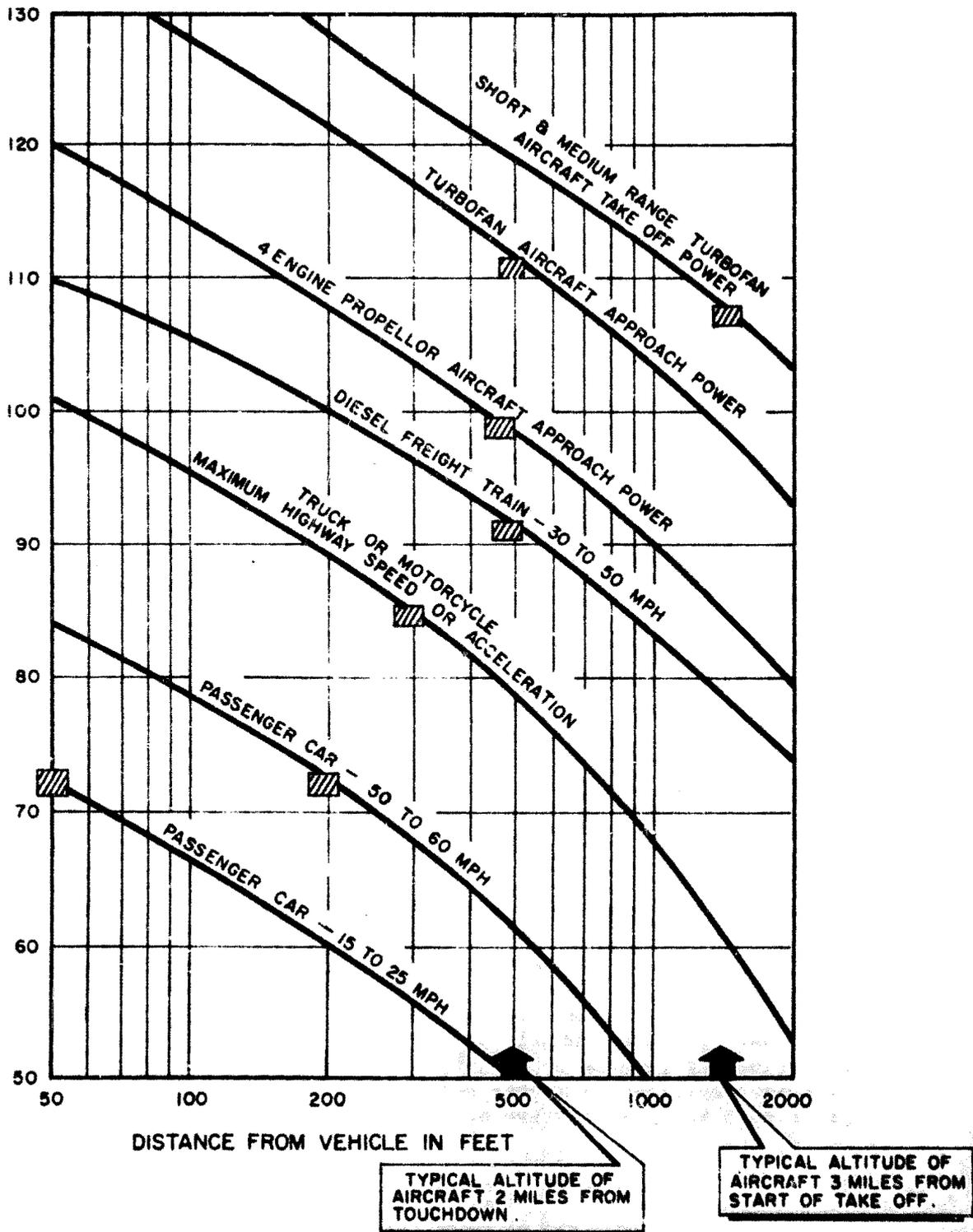


Figure 3. Typical PndB values for vehicle noises heard at a distance (after Kryter (13)). The shaded areas show estimated PndB levels at residence nearest to the noise source.

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others using any of the previously mentioned acoustic measures, need also include data about the duration and number of occurrences of such noise conditions. One sociological study has found, in fact, that doubling the number of occurrences per day of a particular vehicle noise produced the same degree of community annoyance as keeping the number of occurrences constant but increasing the perceived noise level by 4.5 PNdB (14). Laboratory studies have shown that, within limits doubling the duration of a sound increases its judged noisiness by 4.5 PNdB (15).

Other factors that may influence a community's reaction to noise can be psycho-social in nature. Based on case histories, it has been shown that the number of noise-annoyance complaints vary with the urban, suburban, or rural characteristics of the impact area, and with the extent of its previous conditioning to noise or other irritants (16, 17). Time of occurrence is also a significant factor, people being less tolerant of noise in the evening than during the daytime. Adjustments are made in noise rating procedures to take account of these variables in forecasting the community's response to a given noise exposure. These forecasts serve several purposes, one of which is to determine how much noise reduction will be needed before the noise-maker is accepted by the area inhabitants.

This brings us to the main concern of this paper, noise control in transportation systems. The control measures described here reflect three basic approaches to the transportation noise problem. The first deals with aspects of site selection, and the second with barriers. The third approach considers noise reduction gained through design and construction changes in certain kinds of transportation facilities.

SITE CONSIDERATIONS AND NOISE CONTROL

Community noise problems posed by transportation systems can be minimized by choosing sites for these installations which take account of the existing and planned uses of the surrounding land. For example, locating a facility near large industrial and commercial areas offer possibilities for buffering or masking the noise that may radiate from the transportation system to outlying communities. Similarly, installations built in undeveloped regions should require

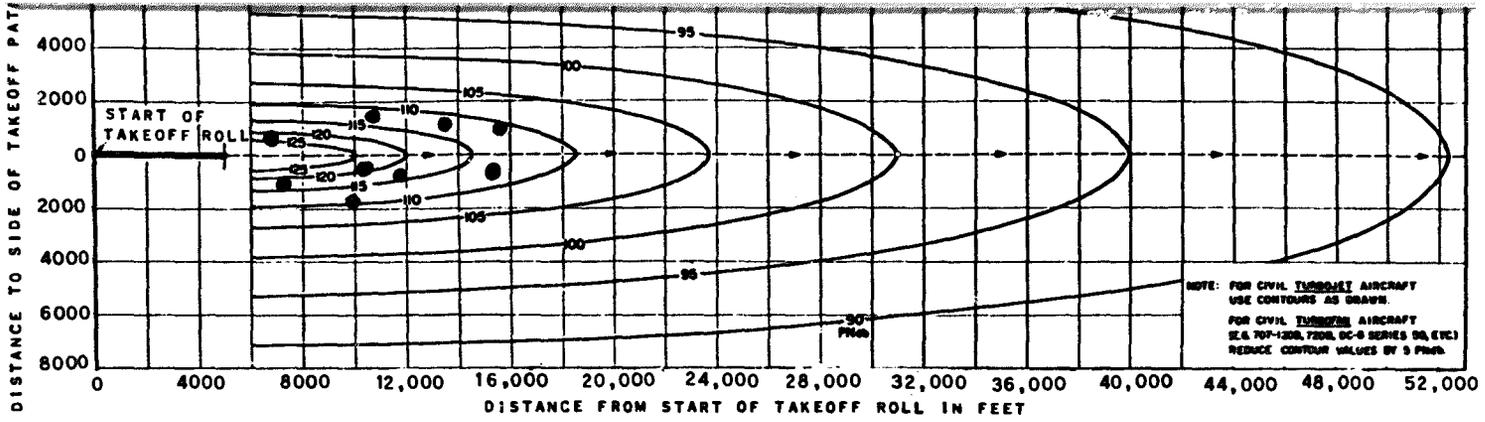
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that the neighboring land be zoned for non-residential use. If not, the facility should buy ample land to take care of future expansion, due to increased traffic, perhaps larger and noisier equipment, and yet retain adequate size clear zones enabling the generated noise to drop off to levels not unlike those found in the nearest inhabited area.

Failure to consider these provisions has led to the present day problem of aircraft noise intrusion in communities near airports. Specific to this airport problem, different guides have been formulated for estimating the community's response to noise generated by aircraft operations; their purpose being to guide zoning decisions and land use planning in the airport vicinity (13, 14, 18). In one guide (18), noise contours, expressed in PNdB, are given for take-off, landing and run-up operations for various classes of aircraft. Examples of these PNdB contours for take-offs and run-ups of long-range jet aircraft are shown in Figure 4. (For the purpose of illustrating incompatible land use, points are plotted on the take-off contours approximating the location of several communities, relative to an airport runway, where vigorous and repeated group protests have been recorded to the intruding aircraft noise.⁽¹⁾ The PNdB levels at many of these locations indicate truly intolerable noise conditions.

In using this guide, the PNdB contours for take-off and landing operations of different aircraft are applied to each airport runway and then corrected to account for total number of movements on that runway, percentage of runway utilization and other factors according to the scheme shown in Table 1. Engine run-up noise contours are evaluated separately by a similar scheme not shown here. These corrected PNdB contour values are referred to as "composite noise ratings" (CNR) which are associated with an expected community response as determined from case histories of airport-community noise problems. This association is described in Table 2 which classifies three zones of response, namely, no complaints, individual vigorous reaction, and concerted group action with increasing CNR or corrected PNdB levels for aircraft operations. Working with this relationship, one can construct the three zones of community reaction

(1) This information was obtained from the Congressional Committee hearings on airport noise (1), the plotted locations being those of witnesses testifying to the severity of the aircraft noise problem in their communities.



TAKE-OFF FOR LONG DISTANCE JET (TRIP >2000 MILES)

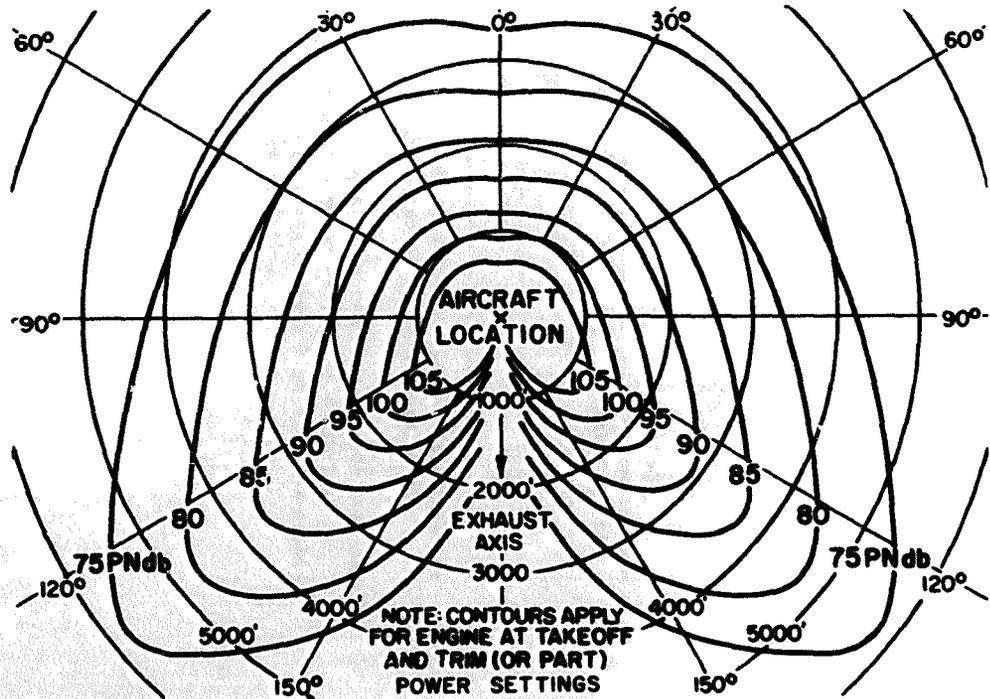


Figure 4. PNdB contours for take-offs and run-up operations of long range jet aircraft (data given in Ref. 18). The plotted points in the take-off contours give locations of some communities which have protested airport noise intrusion.

Table 1. Operational Corrections to Apply to Perceived Noise Levels for Takeoffs and Landings.

Number of Takeoffs or Landings Per Period		Correction
Day (0700-2200)	Night (2200-0700)	
Less than 3*	Less than 2	-10
3-9	2-5	-5
10-30	6-15	0
31-100	16-50	+5
More than 100	More than 50	+10
Percent Runway Utilization		Correction
31-100		0
10-30		-5
3-9		-10
Less than 3		-15
Time of Day**		Correction
0700-2200		0
2200-0700		+10

*If the average number of operations for an aircraft type is less than one per time period, that aircraft type should not be considered in the analysis.

**In general, the ratio of daytime-to-nighttime operations is such that daytime operations determine the Composite Noise Ratings at airports.

Only when the nighttime activity is disproportionately high will the nighttime correction affect the Composite Noise Rating.

Table 2. Chart for Estimating Response of Residential Communities from Composite Noise Rating. (From Ref.18)

Composite Noise Rating *		Zone	Description of Expected Response
Takeoffs and Landings	Runups		
Less than 100	Less than 80	1	Essentially no complaints would be expected. The noise may, however, interfere occasionally with certain activities of the residents.
100 to 115	80 to 95	2	Individuals may complain, perhaps vigorously. Concerted group action is possible.
Greater than 115	Greater than 95	3	Individual reactions would likely include repeated, vigorous complaints. Concerted group action might be expected.

*Corrected PNdB Levels

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for the flight operations found at a given airport. This is shown for a hypothetical two runway airport in Figure 5, the Zone 1 area demarking a region free of significant reactions to aircraft noise, and thus suitable for residential use. If engine run-up noise also is a source of annoyance to the airport neighbors, the noise contours for these operations would be super-imposed on those for the flight activities. The resulting set of curves, defining the various zones of reaction for both types of operations, could look like that given in Figure 6.

The guide just described can be used in alleviating existing noise problems by suggesting new runway construction which could decrease the noise intrusion in populated areas. A hypothetical case to illustrate this application is shown in Figures 7 and 8. Figure 7 shows an existing airport whose operations along one runway (14 & 37) produce significant noise-annoyance problems in communities lying to the north and south. Figure 8 shows a new runway, whose orientation is not too dissimilar from the old one, but whose use will cause a lower level of noise radiation into these same two communities. The guide could also serve to estimate noise reduction from lengthening existent runways or altering flight profiles.

There are some acute airport community noise problems which can only be corrected through purchase of extensive residential land areas. While this remedy may be extremely costly, the eventual resale of this land for more compatible usage might offset any financial loss involved in such transactions.

Community growth and roadway development also reveal incompatibilities in land use resulting in undue noise conditions in residential areas. In alluding to this problem, Thiessen (19) notes how communities tend to grow by stretching out along the main roads emanating from the town center. This is depicted in Figure 9 which shows an aerial view of a town of 30,000 population covering an area of 1,000 acres. While local roads are not shown, the close proximity of the residential areas to the 10 major roads leading out from town would suggest that a large portion of the populace is exposed to high level traffic noise. This view is to be contrasted with the one in Figure 10 which redistributes the different areas for purposes of traffic noise control. Again, local roads are not shown. Only the street that represents the boundary between the commercial and residential areas can now be

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considered as producing significant roadway noise exposure. Comparison with Figure 9 would indicate that the redistribution reduces the exposed population by a factor of 9. In addition, no residential area now butts on an industrial one which may minimize the annoyance of radiating industrial noise.

In reference to community development and roadway noise, Thiessen states, "The major obstacle to effective planning of roads and communities, whether for the sake of minimizing noise nuisance, easing traffic congestion or for any other public advantage, seems to lie in the fact that the authority of planning bodies is generally of a permissive nature. The initiative comes from the private developer who has no knowledge or interest in the amenities just noted. In fact, very often the ills do not materialize until a variety of developers have all added their bit to the random growth of the community" (19, Pg. 12).

Obviously, the best interest of roadway noise control could be served if new communities would not be permitted to encroach on existing busy roads nor new roads on existing residential areas. With regard to the latter, it was encouraging to learn that the Department of Housing and Urban Development is considering potential noise radiation, as well as glare and vibration, as planning factors in routing the 2500 miles of urban highway still to be built as part of the Federal inter-state highway system (20). By-passes and ring roads have been of help in relieving traffic congestion in the centers of towns with resultant reduction in noise. However, routing of such roads requires careful consideration to avoid bringing heavier traffic close to existing schools, hospitals, and houses in other areas which are more vulnerable to noise than are the shops and commercial buildings which often front main roads.

Concerns about community noise problems in airport and roadway planning have not generalized to railway systems. Surprisingly, the number of complaints to railroad noise seems relatively small, but may increase considerably with the advent of high speed rail transportation, including the use of jet powered locomotives. The adequacy of present clearance areas around tracks for serving as a buffer against the expected higher noise levels of these faster trains would certainly appear dubious, and effective control of such noise may require rerouting of track, erection of barriers along rail sites and still other measures, perhaps total enclosure of the system.

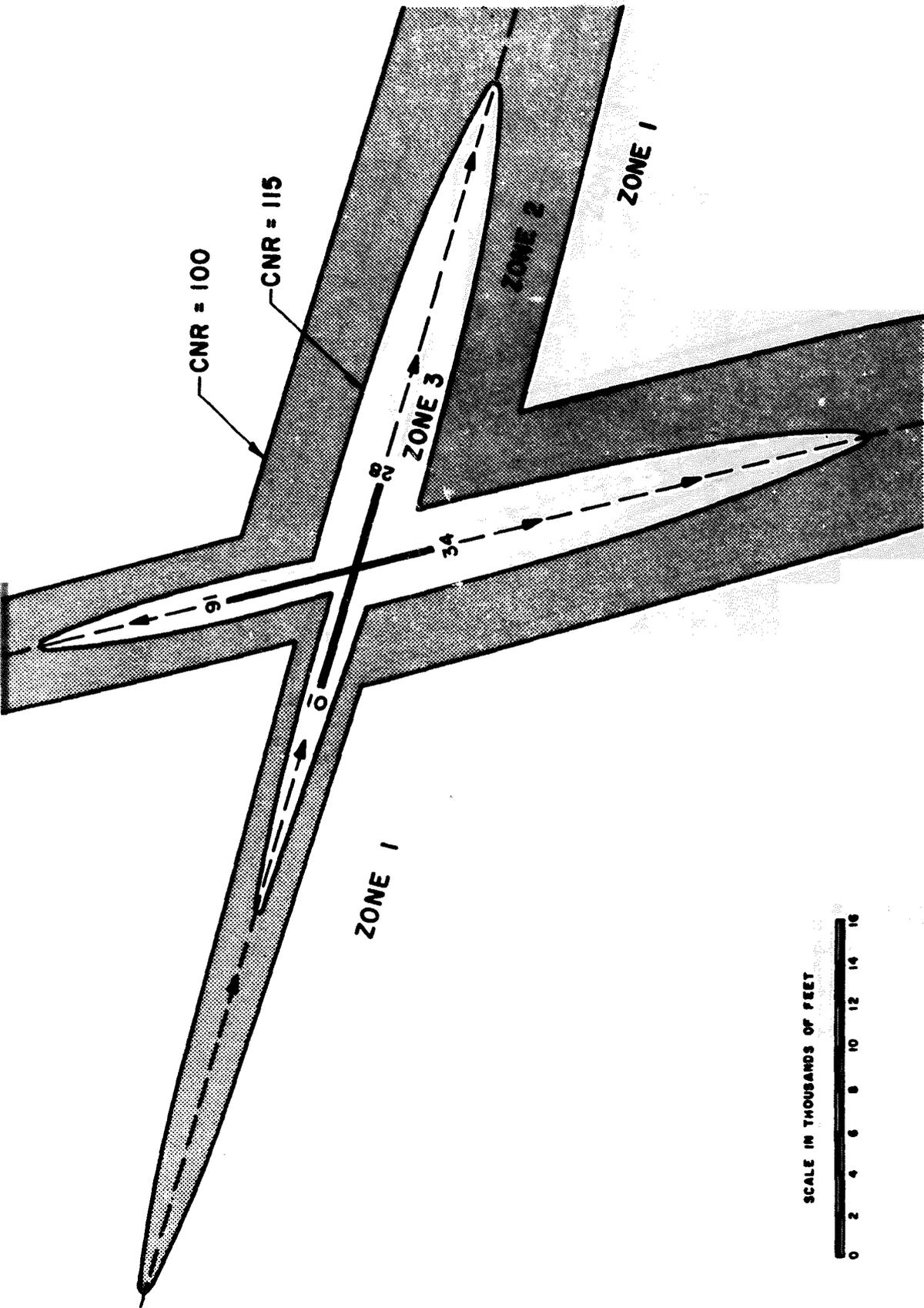


Figure 5. Various zones of expected community response to noise of runway operations at a hypothetical airport.

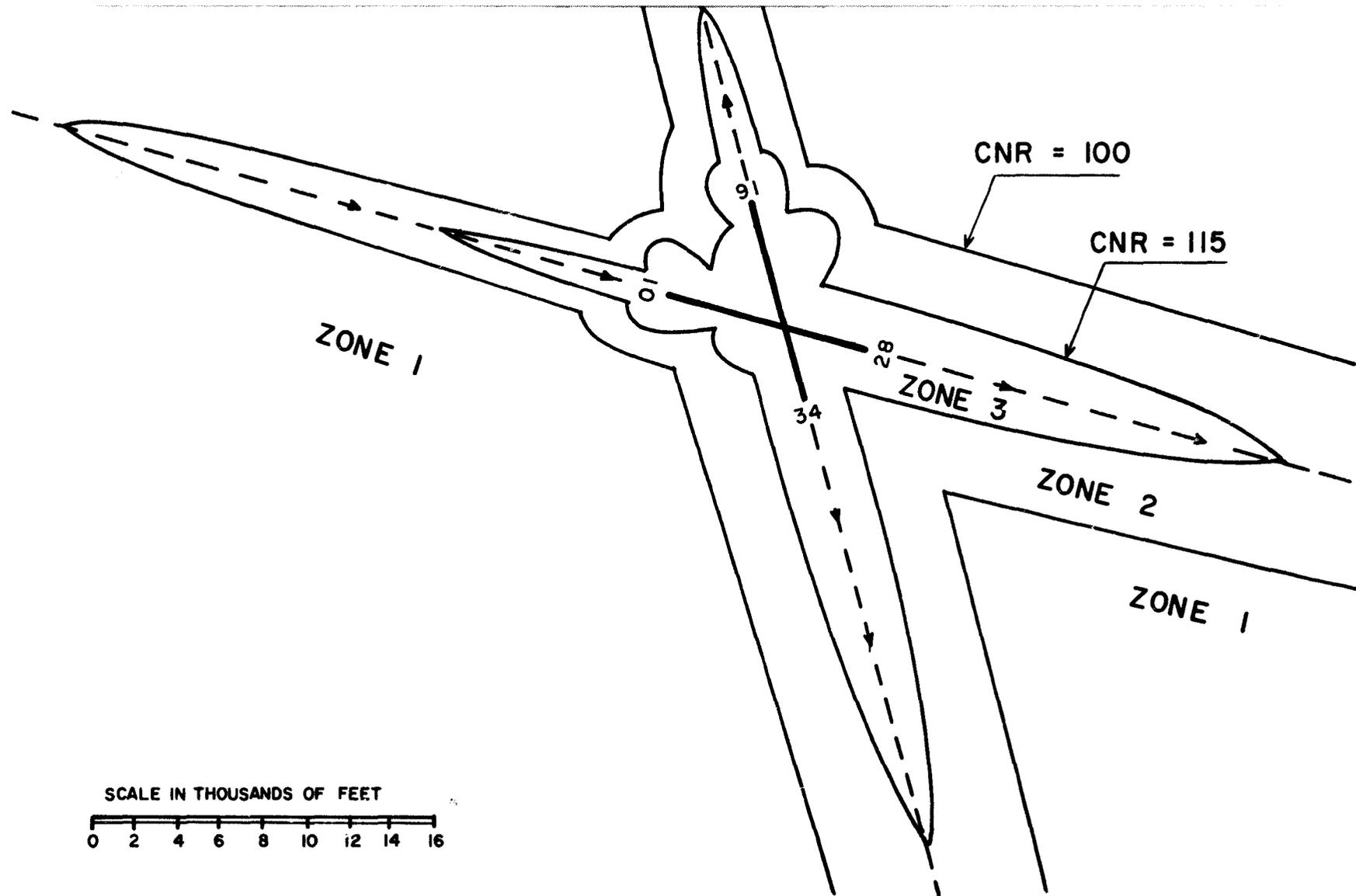


Figure 6. Example of zones of expected community response to both runway and run-up operations at a hypothetical airport.

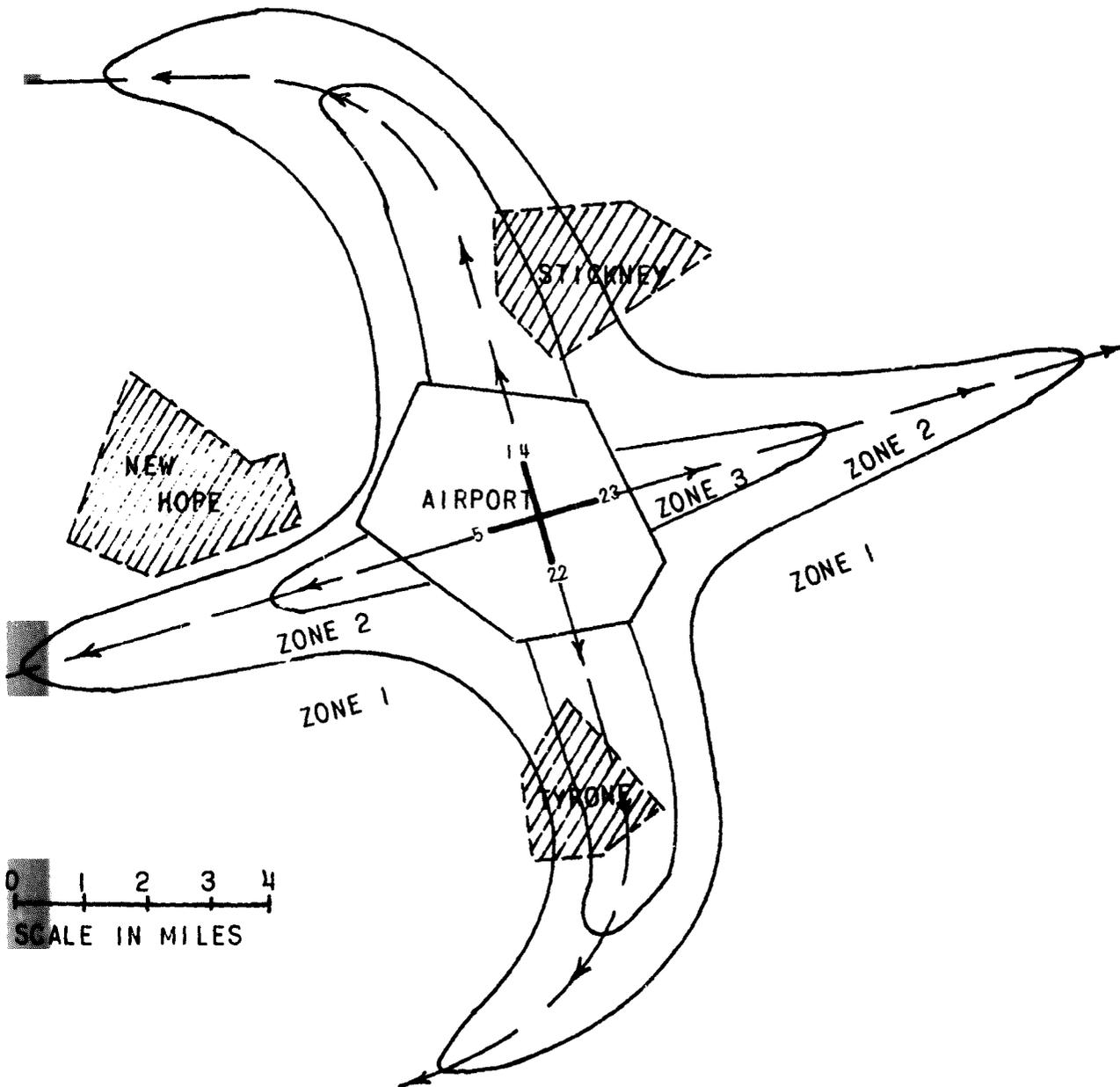


Figure 7. Noise contours around a hypothetical airport showing marked noise intrusion in communities from operations along one major runway. (Example adopted, in part, from Ref. 38).

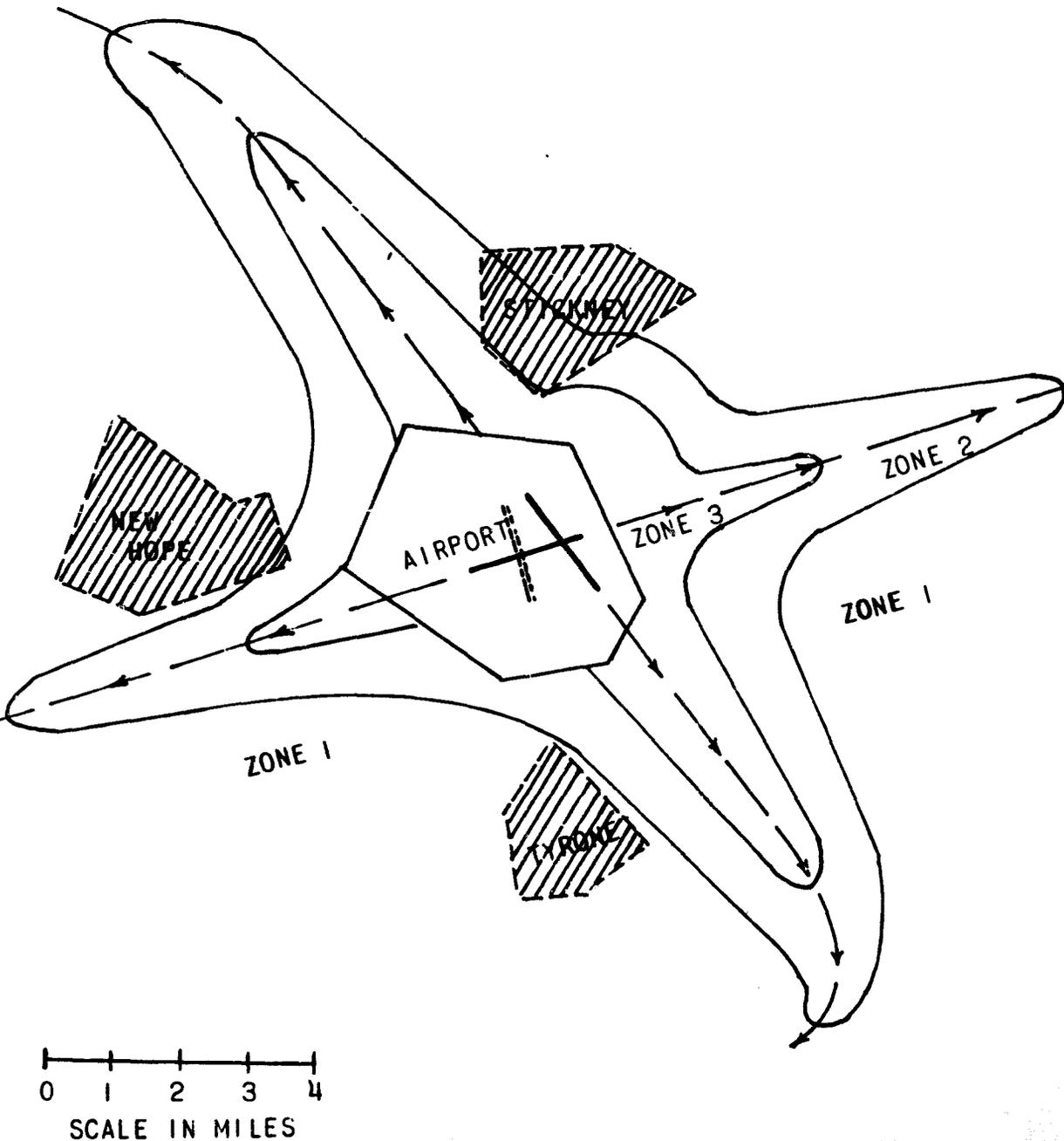


Figure 8. Resulting changes in noise contours around a hypothetical airport from new runway construction, effectively reducing the amount of noise radiating into populated areas. (Example adopted, in part, from Ref. 38).

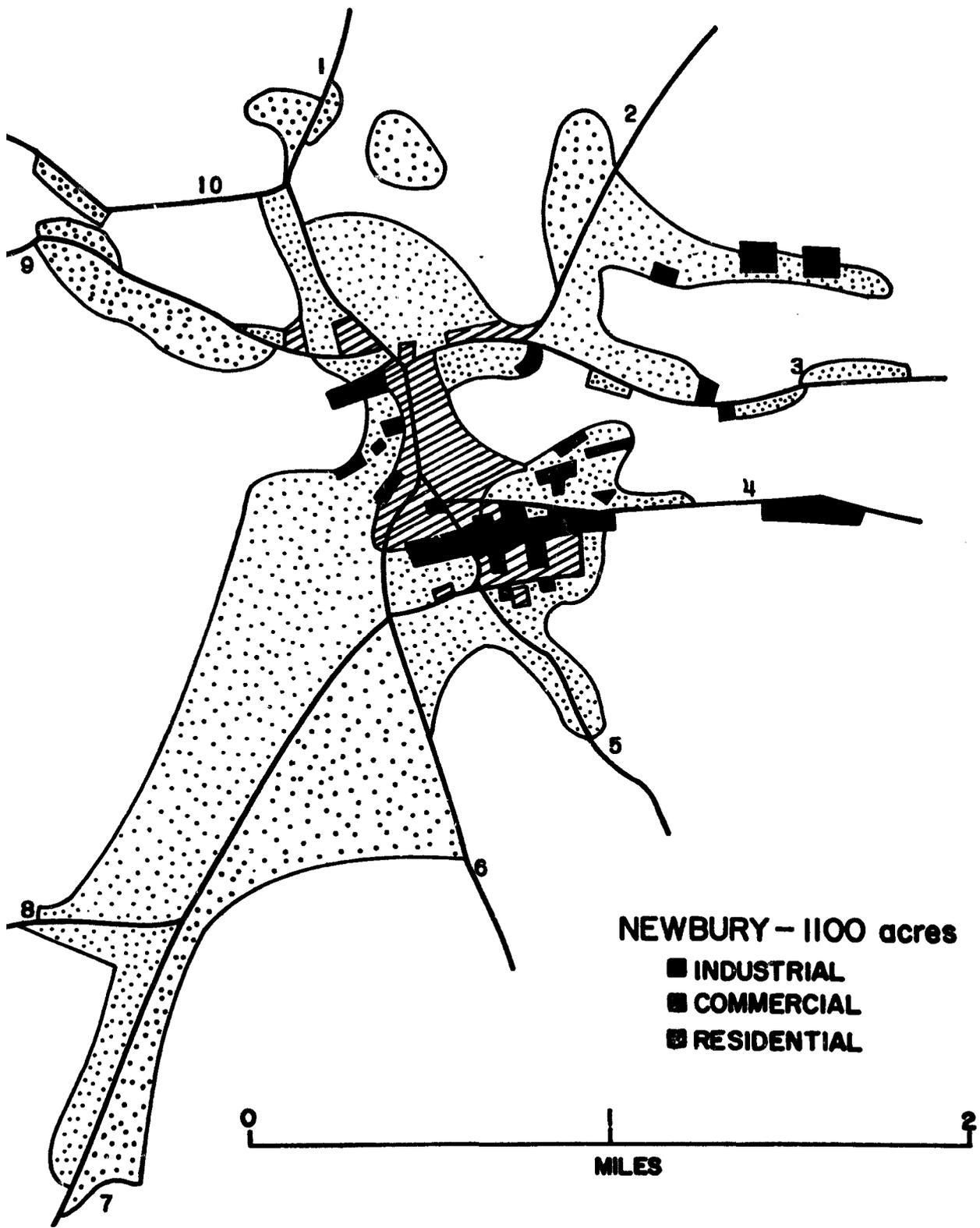


Figure 9. Aerial view of town of 30,000 population covering area of 1,000 acres (example taken from Thiessen, Ref. 19).

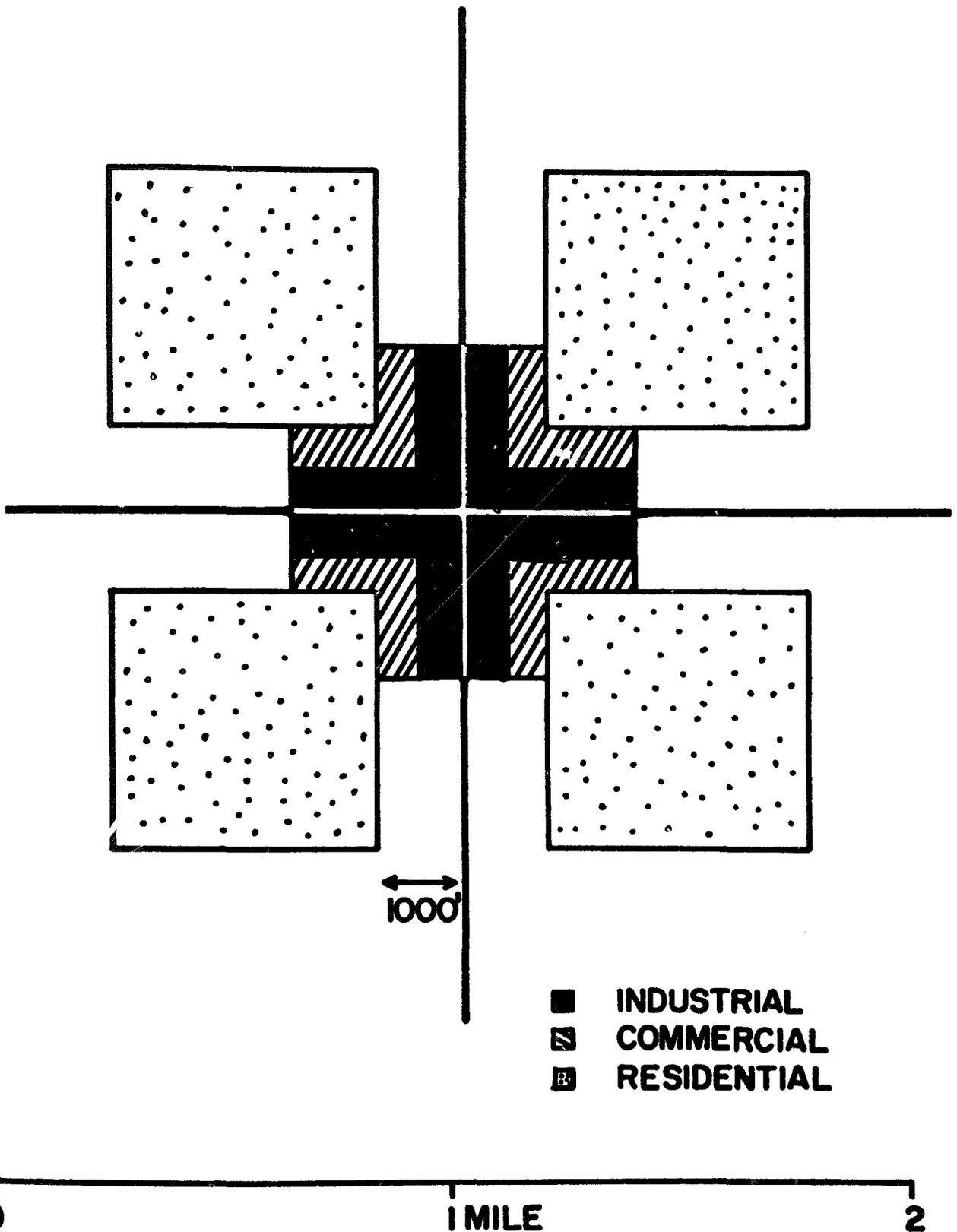


Figure 10. Redistribution of town and community areas to reduce exposure to high level traffic noise (example taken from Thiessen, Ref. 19).

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NOISE REDUCTION BY BARRIERS

Walls, buildings, embankments and other large, rigid barriers, if placed between a sound source and receiver, will attenuate the amount of sound reaching the receiver. This attenuation is in addition to that produced by distance. Figure 11 shows the key variables influencing barrier attenuation as described by Rettinger (21). They are (H) the height of the barrier relative to the noise source, (A) the distance between the source and the barrier, and (B) the distance between the barrier and the receiver. Shown in the lower portion of the figure is the amount of excess attenuation produced by a barrier for the typical case when distance (B) is much greater than the barrier height (H) which in turn is equal to or greater than distance A. The terms 'f' and 'c' in the abscissa expression refer to sound frequency and velocity, respectively. The plotted curve shows attenuation to increase with increasing barrier height and/or decreasing distance between the sound source and barrier. While no limit is indicated for the amount of barrier attenuation, a maximum of 25 dB seems obtainable in practice (22). Figure 12 shows Rettinger's (21) calculations of sound attenuation by frequency as a function of barrier height for fixed source and receiver distances from the barrier. Note how the attenuation for all frequencies increases with increasing barrier height, with the higher frequencies showing more reduction than the low frequencies. This greater attenuation of high frequency sound is significant for control of community noise problems since, as already noted, such sounds are judged more annoying than the lower frequencies (7).

With certain qualifications, the attenuation effect of a barrier is quite similar to that produced by a cut or depression (23). For the same fixed distances A and B, the barrier and cut configurations shown in Figure 13 provide the same acoustic shadow at the position of the receiver, thus causing the same amount of attenuation (22.5 dB) when compared to the unshielded case. Actually some sound, particularly of low frequency, is diffracted into the shadow area. Note that the depth of the cutting must be greater than that of the barrier height to cause the same attenuation. Further, a true depression might even produce less attenuation than that noted if reflections from the far wall are considered as shown in the upper part of Figure 14. Such reflections tend to reduce the effective height of the sound shadow. Sloping the walls of the cut can direct these reflected sounds upward and therein eliminate the problem but also, unfortunately, reduce the effective barrier height for the sounds coming directly

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from the source. Other solutions involve the erection of a partial roof or overhang on the walls of the cut or use of dense planting on embankments to scatter and absorb reflected sounds.

The effectiveness of a cut in reducing radiating train noise has been reported by Embleton and Thiessen (24) and is illustrated in Figure 15. The dimensions of the cut are shown as are the range of octave-band sound levels for freight train noise measured at 100 feet from the edge of the embankment. For comparison purposes are shown the ranges of octave-band readings for the train, measured at the same 100 foot distance, with the track roughly at the same grade as the surrounding land. The sound attenuation produced by the cut is substantial, midpoints of octave-band levels for the cut condition being in some instances as much as 23 dB less than the "same grade" condition. Comparison of the midpoints of these two sets of octave-band data, if expressed in PNdB, would indicate that the cut would more than halve the perceived noisiness of train noise.

Barriers rather than depressions have been suggested for reducing potential noise problems of new roadways since depressed roads are more costly to build considering the amount of earth that has to be removed and the need for drainage. The presence of a high barrier for long stretches of road however, would provide a rather dreary view to the motorist. Hence, barriers of limited height, e.g., 3 1/2 feet, permitting visibility of the surrounding area have been suggested (19). While these limited barriers would offer some reduction to noise of high frequency, they would give negligible attenuation for the strong low frequency noise of trucks - perhaps the worst roadway noise makers. They also would have to contain breaks to accommodate incapacitated vehicles which would serve as acoustic leaks unless otherwise shielded.

Barriers in the form of long, fairly tall buildings have been suggested for controlling the spill-over of airport noise into surrounding residential areas (25). Such buildings would run along the entire boundary of the airport, parallel to the airport runways. One acoustic expert's view of this plan is sketched in Figure 16, the structure being an 8-story apartment building of about 100 feet in height. Sound treatment inside the building would suppress the outdoor aircraft noise to low levels, while the building itself, acting as a barrier would cause approximately 25-30 dB noise reduction

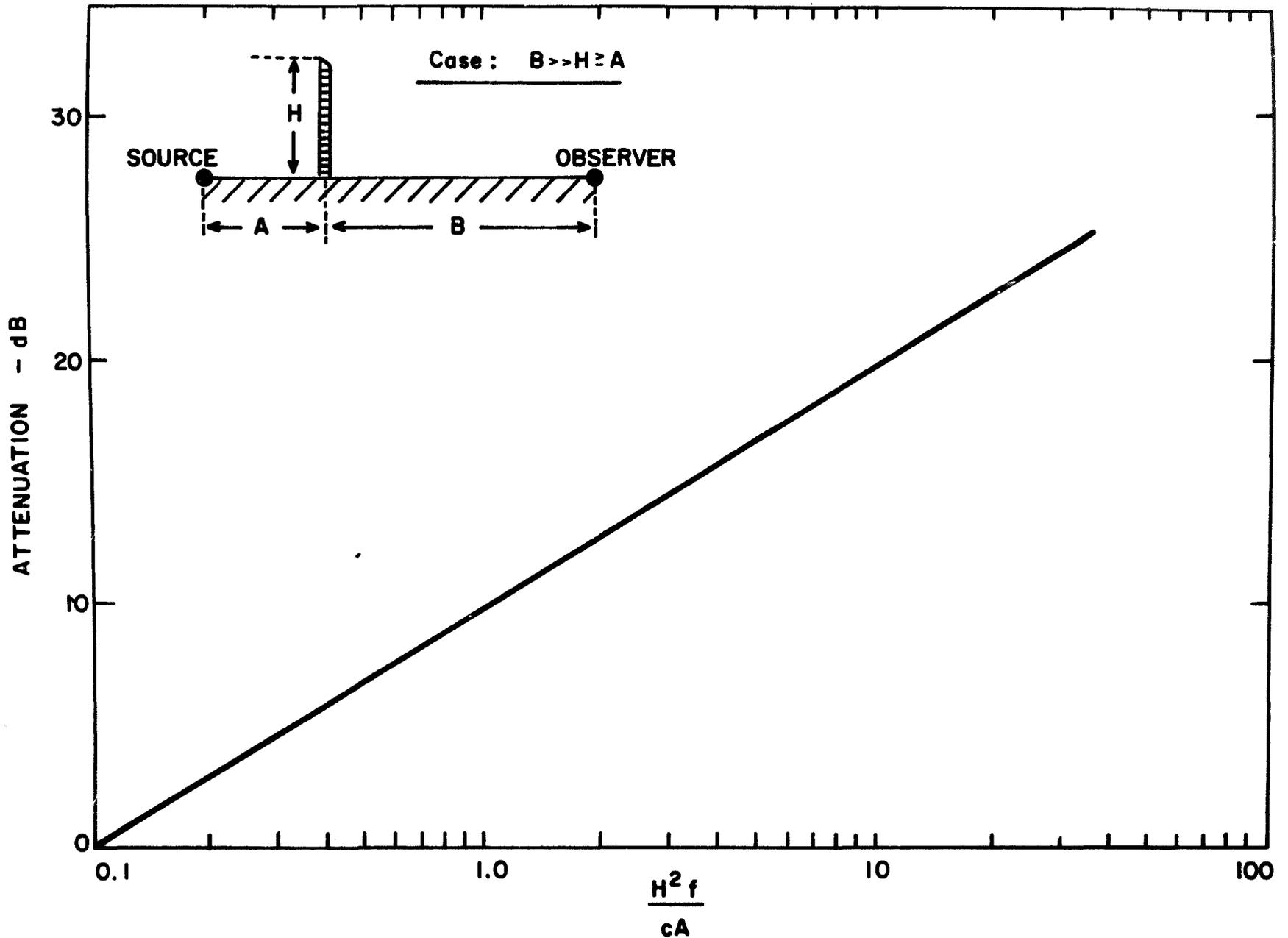


Figure 11. Key factors influencing barrier attenuation of sound (after Rettinger (21).)

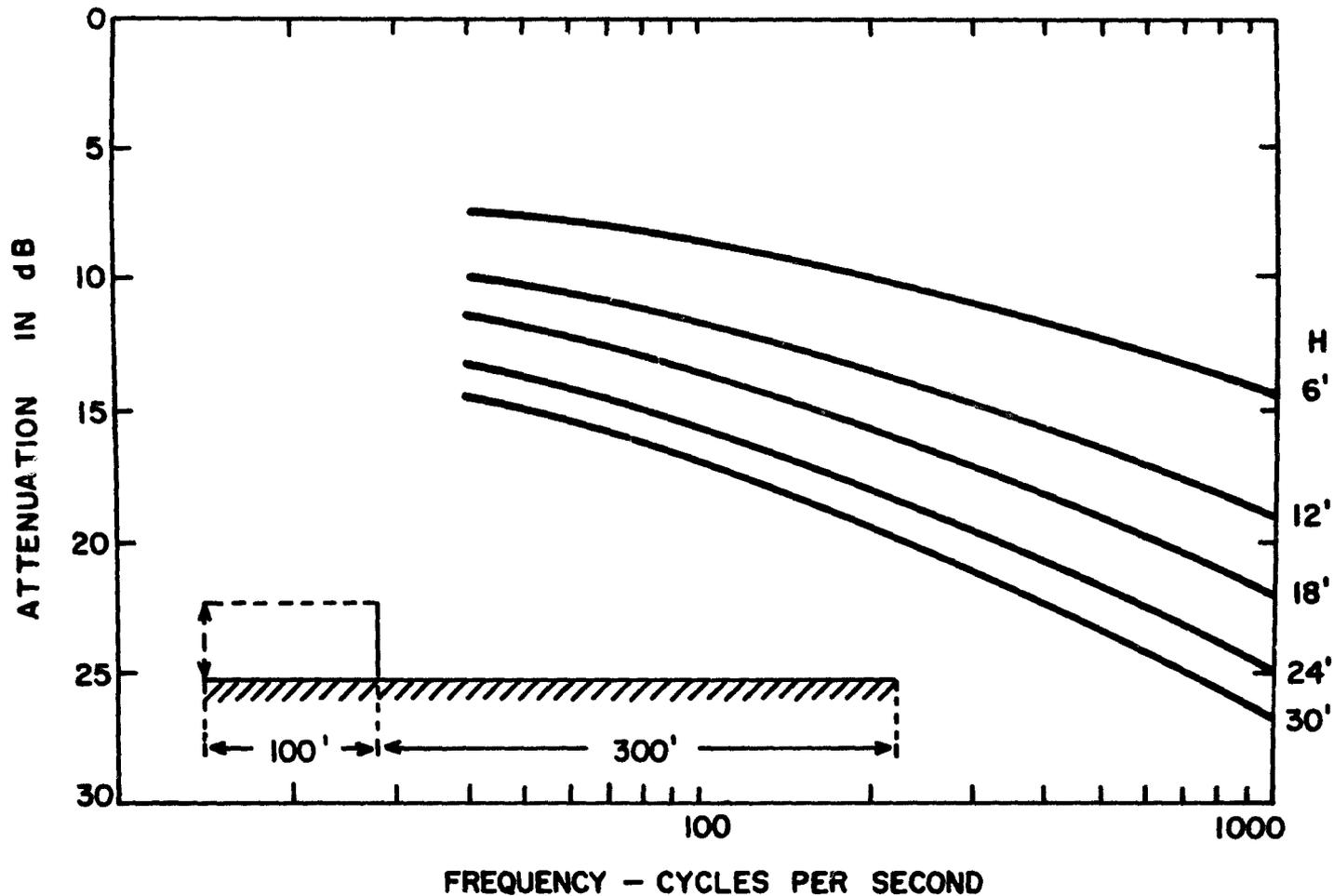


Figure 12. Sound attenuation by frequency as a function of barrier height for fixed source and receiver distances from the barrier (after Rettinger (20).)

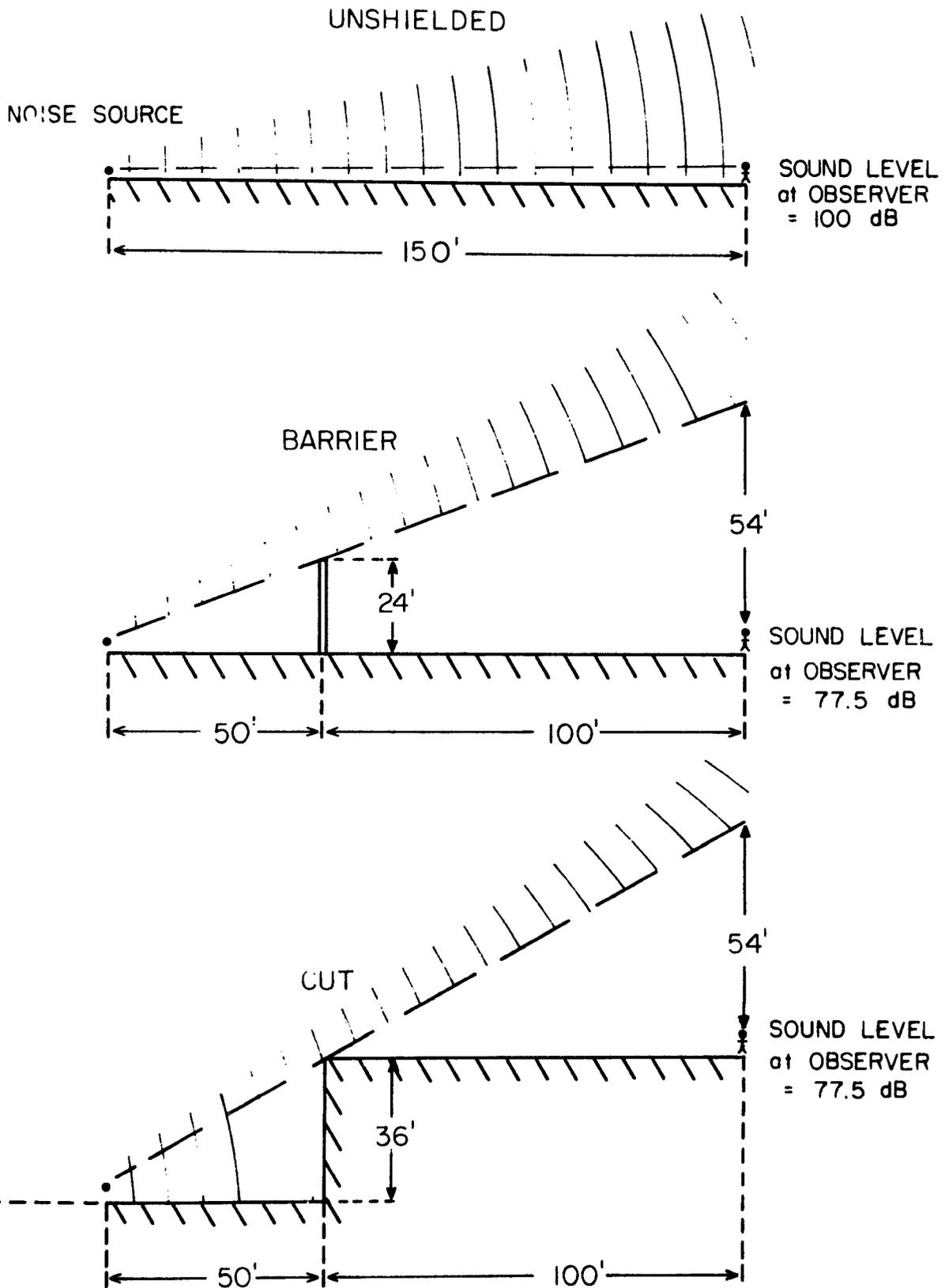


Figure 13. Sound attenuation provided by a barrier and depression as compared with unshielded case. (Example taken from Rettinger (22).)

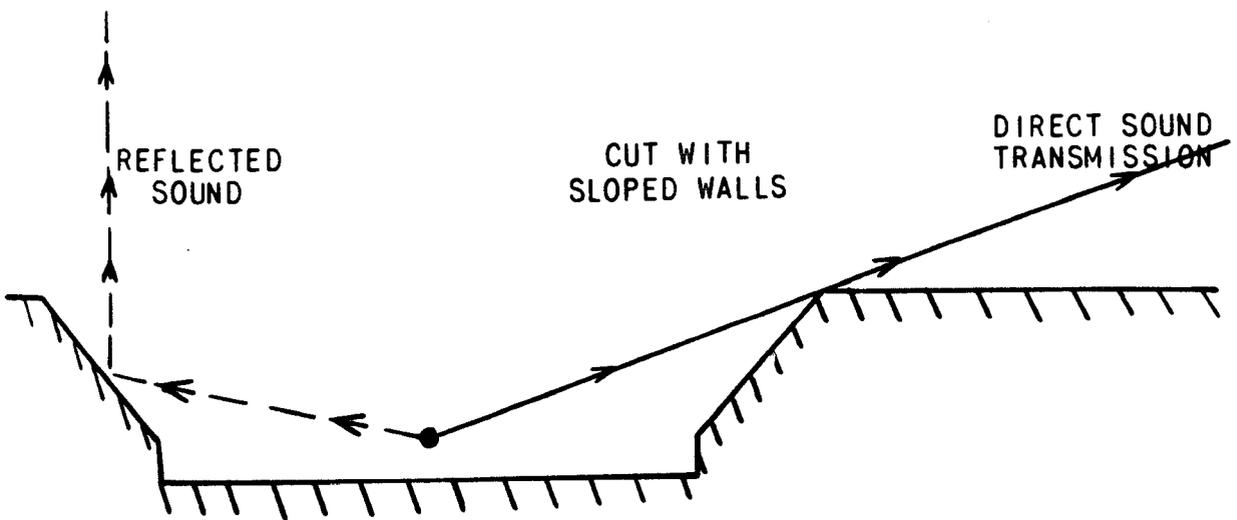
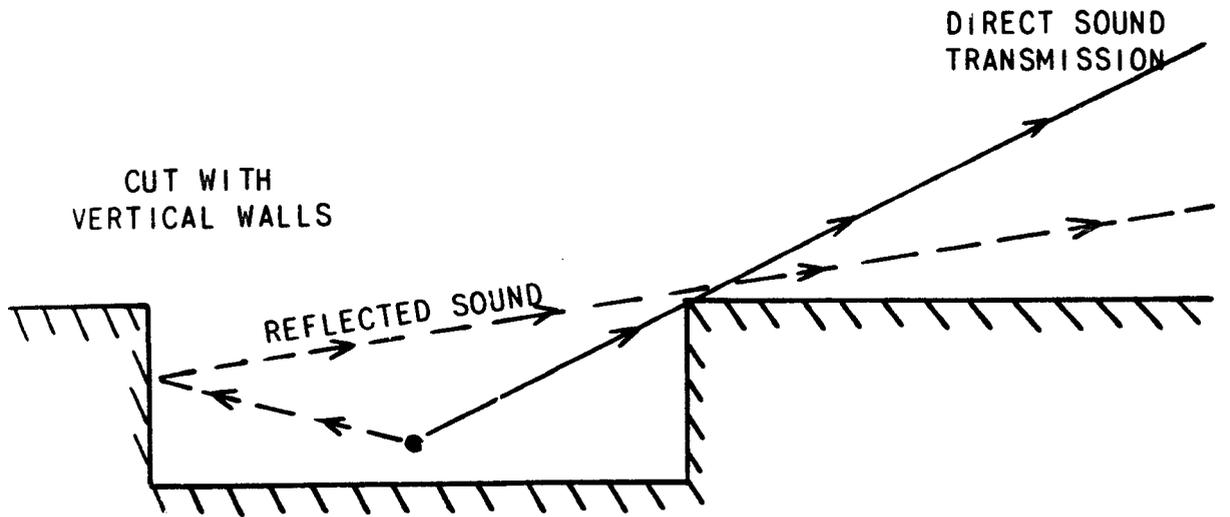


Figure 14. Effects of sloping the walls of a cut on sound reflections and direct sound transmissions from the source.

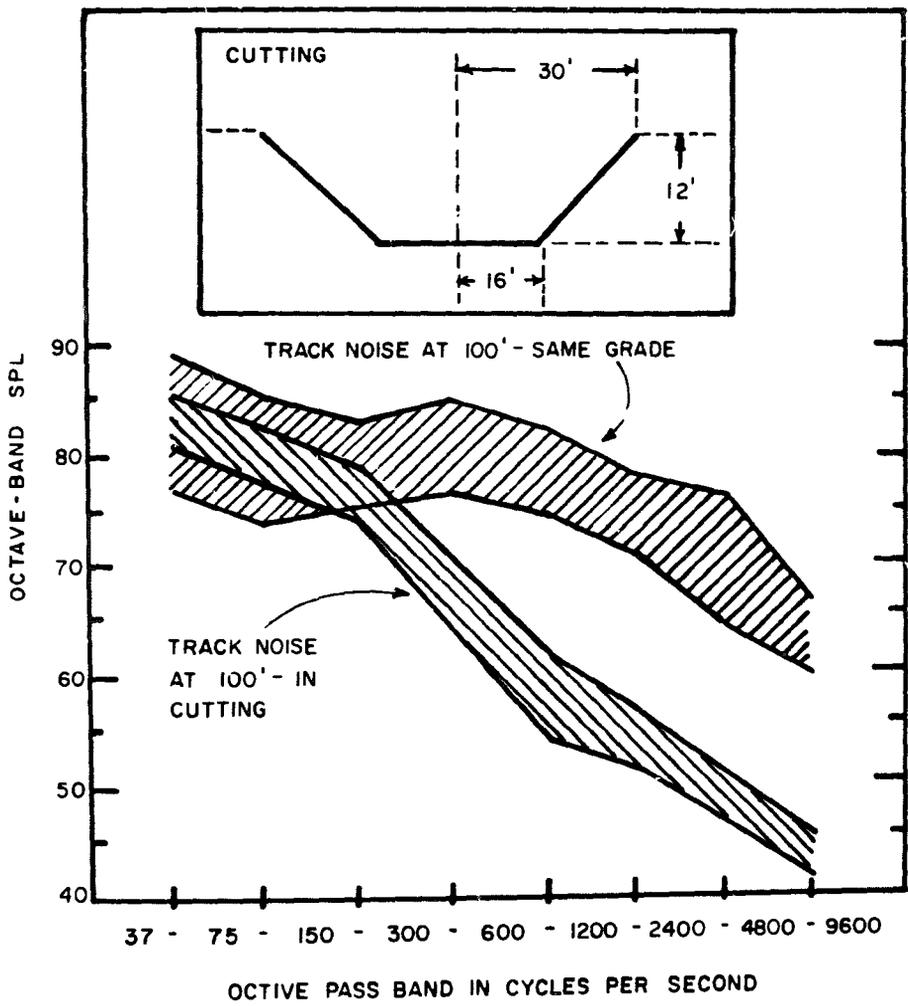


Figure 15. Reduction in amount of radiated train noise caused by depressing rails. (Example taken from Embleton and Thiessen (36).)

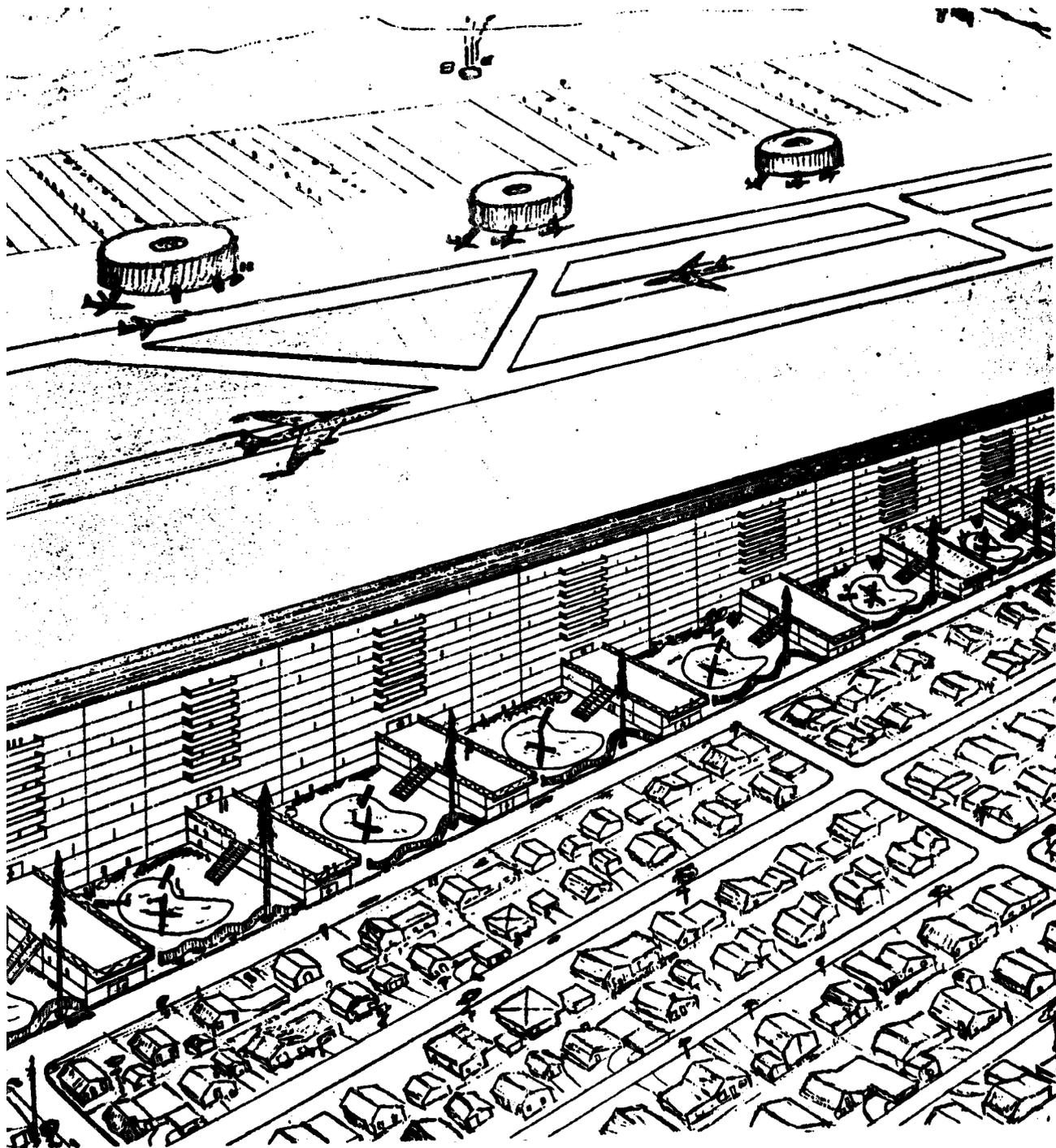


Figure 16. Use of buildings lining an airport boundary for purposes of shielding outlying communities from undue airport noise (see Ref. 23).

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in the adjacent community. While the basic plan has merit, the desirability of using such buildings for apartments is certainly questionable in view of crash possibilities. Many complaints to aircraft noise by residents around airports are believed motivated, in fact, by the fear of an aircraft disaster (26). Using such buildings for warehousing may be more reasonable.

The attenuation of trees and forests have been studied with the findings showing that hundreds of feet of dense planting would be necessary to create an effective sound barrier (27, 28). Figure 17 shows the approximate decibel reduction per 100 feet of woods in excess of that produced by distance by octave-band frequencies. Using this data and the roadway noise spectrum referenced earlier (see Figure 1), one could estimate and compare the resultant noise levels at various distances from a roadway, given bordering strips of clear and wooded land. This comparison is shown in Figure 18, the wooded area causing lower radiated noise levels for each specified distance. Expressing the spectral data in Figure 18 in PNdB, the wooded strip widths of 50 feet, 150 feet and 350 feet, would result respectively, in 16%, 21%, and 40% less noisiness when compared to equal widths of clear land.

The minimum width of planted areas needed to attain truly significant attenuation of roadway noise is believed to be 200 feet which may make such treatment measures unfeasible. It must be noted, however, that merely hiding a roadway or other offensive noise source from view by trees and shrubs can offer marked psychological attenuation of intrusive noise, resulting in fewer complaints.

NOISE REDUCTION THROUGH MODIFICATION OF TRANSPORTATION FACILITIES

High speed expressways in city areas carry dense traffic under, over, and alongside occupied buildings. Much of the airborne noise of this traffic is attenuated by building walls and presents only minor problems. On the other hand, this traffic movement may cause sound transmission into building areas via connecting structures, creating significant noise problems to the occupants. Limited data have shown structure-borne noise levels in buildings located beside or over a

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medium speed highway to range from 60 to 80 dB in the 20 to 75 cps octave-band and drop off with frequency at the rate of 10 dB per octave (29). Miller (29) offers some general suggestions for suppressing sound transmissions of this nature. They are:

- a) Have no expansion joints in the roadway near critical buildings.
- b) Have no drainage grills running across the roadway.
- c) Provide suitable vibration isolation joints between the roadbed and the structural members of adjoining buildings.
- d) Provide a smooth, fine-grained road finish.

With regard to the latter, little interest has been directed toward developing roadway surface materials which could reduce structure-borne and air-borne roadway noise emission. The application of soft plastic coatings to highway surfaces has been mentioned as a possible means of absorbing tire noise but no evaluative work has been done as yet (19).

Structure-borne noise problems in buildings are also caused by movements of nearby railroad trains or subways below. Reduction of these sound transmissions can be gained through using continuous, welded, steel rails that are kept precisely aligned and free of waves or other imperfections. It is open track joints and other irregularities in the surfaces of contact between the rolling metal wheels and rails which are the principal causes of both structure-borne and air-borne train noise. A more dramatic solution here has been to use railroad cars with pneumatic tires which roll on wide concrete rails. Rubber tired subway trains were first used 10 years ago on portions of the Paris Metro subway system and are to be used in the nearly completed Montreal system. Unfortunately, noise level measurements on the Paris and Montreal systems could not be obtained but would be expected to be much lower than those found for subways using more conventional equipment. On the other hand, it has been learned that Paris is discontinuing its pneumatic-tired trains and returning to the steel-wheeled cars and steel rails. High replacement costs and frequency of replacement of rubber wheels were said to be the reasons for the change.

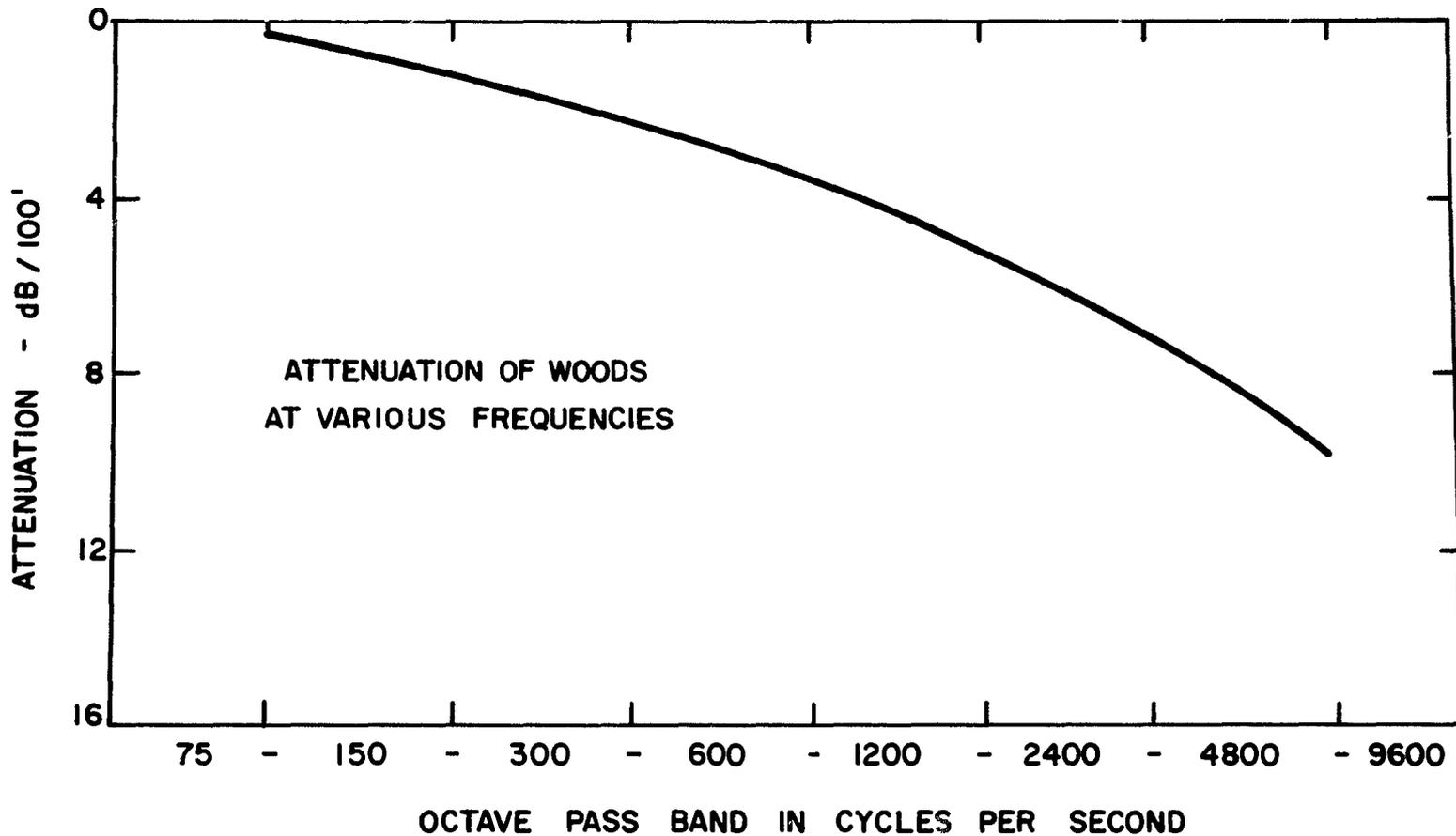
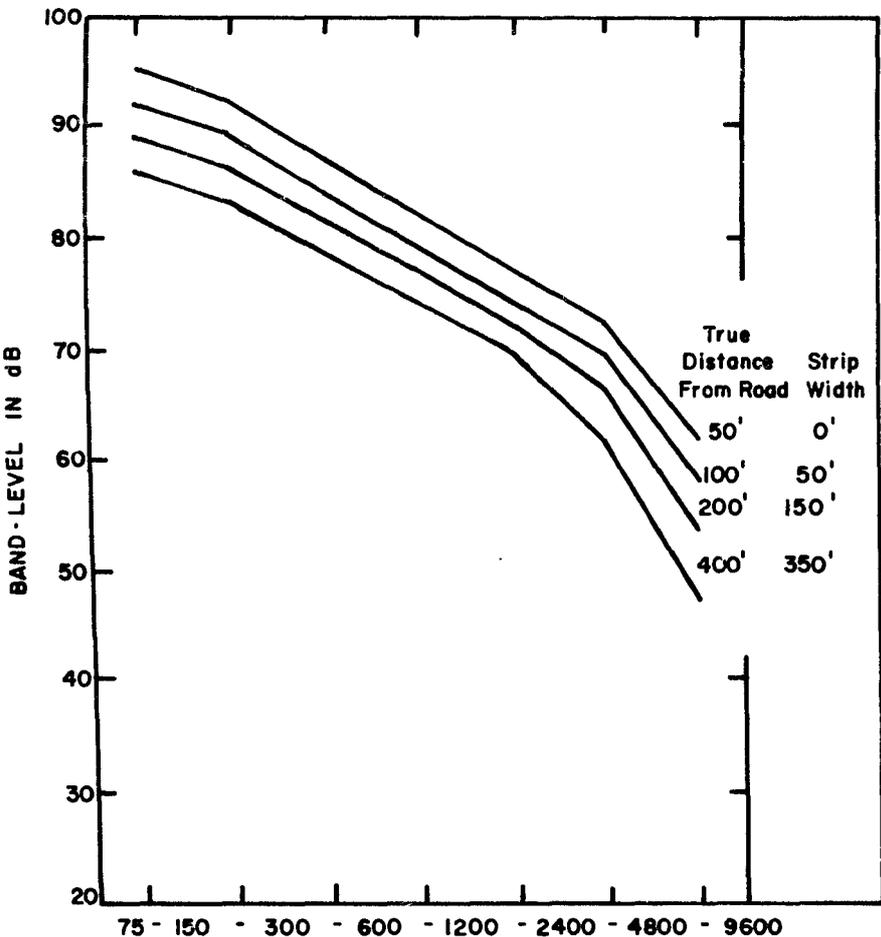


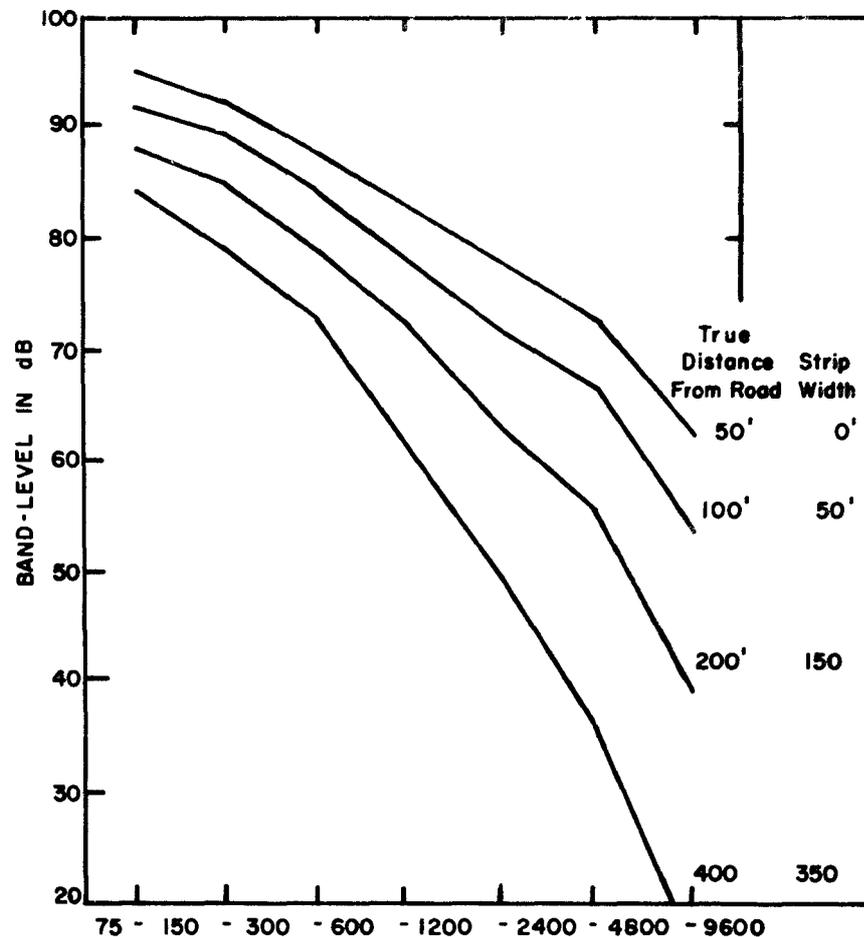
Figure 17. Attenuation in dB per 100 feet of woods at various octave-band frequencies. (see Ref. 18).

BARREN



OCTAVE-PASS BANDS IN CPS

WOODED



OCTAVE-PASS BANDS IN CPS

Figure 18. Computed noise levels in octave-bands, at various distances from a busy roadway, given bordering strips of barren and wooded land. Nomograph given in Ref. 38 (pg. 24) was used to calculate traffic noise levels as a function of distance.

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Vibration isolation of the tracks from the rail ties and roadbed will also reduce structure-borne noise from trains. Reduction of ground transmitted noise from a subway by means of mounting elastic (neoprene) pads under the rails may produce over 20 dB of sound attenuation relative to the uninsulated condition (20).

Some success in curbing air-borne track-side noise in subways has been obtained by erecting horizontal projecting surfaces just above the rails, the undersides of these surfaces being coated with a sound-absorbent material. Over-all noise level reductions of 6 to 7 dB were noted in comparing tunnels having this treatment against untreated ones, as measured inside subway cars with open windows (cited in Reference 31). Perhaps similar reductions would occur in subway stations if the undersides of the passenger platforms were treated with absorbent material.

ADDED COMMENT - SONIC BOOM

This paper would be incomplete without some comment being made about the sonic boom problems from supersonic aircraft operations. Sonic booms from aircraft are associated with shock waves, a natural consequence of supersonic flight in the atmosphere. These waves extend out from the aircraft, being observed on the ground as transient over-pressures of short duration which travel along at the speed of the aircraft, and which spread laterally for several miles on each side of the ground track. Overland supersonic flight tests, approximating altitude and other conditions to be used by future commercial supersonic air transports, have been found to produce over-pressures or booms of 2-2.3 lbs/in² in areas lying within 2 miles of the ground track (32, 33). Individuals living in these impact areas reported some structural damage (cracks in plaster, glass breakage) and as a group complained vigorously about the disturbance caused by the booms. Less intense over-pressures from these flights were noted with increasing lateral distance from the flight path, but even at 8-10 miles the boom pressure levels were still strong enough (1-1.2 lbs/in²) to cause widespread reaction among exposed inhabitants. Other types of tests, comparing the perceived noisiness of sonic booms with other aircraft noises, have indicated that persons indoors in a path 16 miles wide would be bothered by the sonic boom to about the same degree as persons indoors directly under the flight path of a subsonic jet aircraft 1 1/2 miles from an airport (34).

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The large area of impact, the relatively high intensity of the sound and, of course, its startle quality, have caused great concern about the public acceptance of sonic booms. Indeed, the feasibility of routine SST operations, particularly for overland routes, is believed to be largely a function of the severity of the sonic-boom problem. Presently, the best practical methods for reducing the shock wave intensity to tolerable values appear to be restraints on aircraft design and operation (35, 36).

CONCLUSIONS

This discussion of controlling radiation of transportation noise is best summarized by the following conclusions:

1. Planned locations for airports, highways, and rail installations must take account of surrounding land use in order to alleviate potential problems of community noise intrusion arising from operation of these transportation facilities. Siting such facilities adjacent to areas zoned for non-residential use, or acquiring sufficient land to provide sizeable buffer regions between the facility proper and the nearest residence are excellent preventative measures.
2. Walls, embankments, buildings and other large, rigid structures can serve as effective sound barriers against radiating transportation noise. The sound attenuation of barriers depends upon their height, and the noise source and receiver distances from the barrier. Barrier attenuation is greatest for the higher, more annoying frequencies in the noise field. Unless broad areas are available for planting, trees and shrubs will not cause significant reduction in radiating noise.
3. Techniques of vibration isolation, application of sound absorption materials, elimination of irregularities in vehicle contact surfaces (e.g., removal of open track joints, use of smooth-grained road finishes) will serve to reduce structure-borne and air-borne noise generation and transmission.

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4. Sonic-booms from overland supersonic flights of aircraft are expected to cause formidable community noise problems. Restraints on aircraft design and flight operations presently appear to be the only ameliorative measures in dealing with this problem.

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