11 - Advanced Systems

NOISE CRITERIA FOR HIGH SPEED MAGLEV TRAINS

HMMH Report No. 291550-2

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Prepared for:

Federal Railroad Administration
400 7th Street, SW
Washington, DC 20590

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PREFACE

This report is the second of four reports to be prepared under U.S. Department of Transportation Contract # DTFR53-91-C-00074, "Noise from High Speed Magnetically Levitated Transportation Systems." The reports under this contract cover the following areas:

1. Characterization of Noise Sources
2. Noise Criteria for High Speed Maglev Systems
3. Preliminary Design Guidelines based on Noise Considerations
4. Recommendations for Acoustic Test Facility for Maglev Research.

The first report, HMMH Report No. 291550-1, presented information on the noise levels obtained from testing programs on the TransRapid system in Germany, described sources of noise from maglev systems, quantified the potential environmental noise impact from hypothetical systems installed in the United States, and identified further research needs for resolving the unknowns related to sound sources on high speed surface transportation vehicles.

This report presents information on the criteria recommended for use in evaluating noise impact from high speed maglev systems. These criteria describe the noise environment considered acceptable for specific land uses, depending on the ambient noise. These recommendations are based on the best available data related to transportation systems with noise characteristics similar to high speed maglev. As a result the conclusions must be considered based on circumstantial evidence until more definitive methods can be verified.

EXECUTIVE SUMMARY

The introduction of a new transportation system into a community generates concerns about the change in the noise environment brought about by the new source. When the new source has unique features, as does maglev, or when the community has not had prior exposure to a particular source, as will happen with a maglev system, the concerns are heightened. The unknown community reaction to such a potentially significant new development is not an acceptable risk for the builders and financiers during these times of environmental awareness. This report presents a means of rating the noise created by maglev in terms of the disturbance it creates.

Characteristics of Maglev Noise Resulting in Noise Impact

High speed maglev passbys are characterized by high noise levels and brief durations. Maximum noise levels at 25 meters from the guideway range from 77 dBA at 160 km/hr to 98 dBA at 435 km/hr for the TransRapid TR 07. Durations of the noise event depend on the length of the train and the distance of the receiver from the guideway, but for the two-car TR 07 at 435 km/hr, it takes only 3 seconds for the sound to rise and fall to 20 dB of the peak (Figure 1). The onset rate for the 435 km/hr signature is 21 dB per second. Onset rates greater than 15 dB per second are considered to cause "startle," worthy of a 5 dB penalty in an impact analysis. Onset rate depends on speed and distance from the guideway: fast rise times are associated with high speeds and/or close proximity to the guideway.

Maglev noise spectra are generally characterized by broad band distribution of frequencies. However, maglev has the potential of creating pure tones and these are considered to be especially annoying. Penalties of 5 dB are assigned to pure tone sources.

Community Noise Impact Criteria

Community response to noise is related to the total noise energy in a specified time period. The recommended community noise impact descriptor for maglev is the day-night sound level, Ldn, with an "onset rate adjustment" to account for fast rise times. Ldn is a single number "equivalent sound level" in dBA which contains the same acoustical energy as the actual time-varying noise pattern over 24 hours, but with a weighting factor of 10 dB applied to noise that occurs during the nighttime hours of 10 p.m. to 7 a.m. This unit includes the noise effects that are considered to be most important to people's reactions to noise, including:

- Spectral content -- the A-weighting curve corresponds to the way in which humans interpret sound;
- Equal energy considerations -- trade-off between sound level and duration corresponds to 3 dB per doubling of duration; and
- Time of day sensitivity -- nighttime events receive an extra weighting of 10 dB.

The "onset rate adjustment" is an addition of 5 dB to sound exposure levels of each event that exhibits a rise time greater than 15 dB per second.

The noise impact criteria for maglev operations are based on comparison of the existing Ldn and future "onset rate adjusted Ldn" of the maglev operations. These criteria are identical to those proposed by the Federal Transit Administration for assessing noise impact from urban transit operations. The impact criteria are defined by two curves which allow increasing maglev noise levels as ambient noise increases up to a point, beyond which impact is determined based on maglev noise alone (Figure 11). Below the lower curve, a maglev system is considered to have no noise impact since, on the average, the introduction of the system will result in an insignificant increase in the number of people highly annoyed by the new noise. Maglev noise above the upper curve is considered to cause Severe Impact since a significant percentage of people would be highly annoyed by the new noise.

Between the two curves the proposed project is judged to have an impact, though not severe. The change in the cumulative noise level is noticeable to most people, but may not be sufficient to cause strong, adverse reactions from the community. In this transitional area, other project-specific factors must be considered to determine the magnitude of the impact and the need for mitigation, such as the predicted level of increase over existing noise levels and the types and numbers of noise-sensitive land uses affected.

The noise criteria and descriptors depend on land use, designated either Category 1, Category 2 or Category 3:

> Category 1 includes tracts of land where quiet is an essential element in their intended purpose, such as nationally significant historic sites or outdoor concert pavilion.

Category 2 includes residences and buildings where people sleep.

Category 3 includes institutional land uses with primarily daytime and evening use such as schools, churches and active parks.

The procedure for assessing impact is to determine the pre-project ambient noise level and the predicted maglev noise level at a given site, and to determine the impact by plotting these levels on the chart shown in Figure 11. The location of the plotted point in one of three impact ranges is an indication of the severity of the impact.

Example of Application Method

For the hypothetical direct replacement of Northeast Corridor service with 10-car maglev trains at 400 Km/hr in a Boston suburb, noise "Impact" would occur for any residence within 80 m of the guideway and "Severe Noise Impact" would occur for any residence within 40 m. In addition, the potential for startle would occur for any residence within 32 m of the guideway, due to onset rates in excess of 15 dB per second.

1. INTRODUCTION

1.1 Need for Noise Criteria for Maglev

The introduction of a new transportation system into a community generates concerns about the change in the noise environment brought about by the new source. When the new source has unique features, as does maglev, or when the community has not had prior exposure to a particular source, as will happen with a maglev system, the concerns are heightened. The unknown community reaction to such a potentially significant new development is not an acceptable risk for the builders and financiers during these times of environmental awareness. It is important to have a means of rating the noise created by maglev in terms of the disturbance it creates, in order to gauge the community response and to avoid unacceptable installations.

The topic of assessing the impact of a new noise source in the community has been covered extensively by the U.S. Environmental Protection Agency (EPA). Research sponsored by the EPA in the 70's provided the basis for the development of noise descriptors and criteria by other federal agencies including various modal administrations of the Department of Transportation. Among the key findings of EPA research is that the day night sound level (Ldn) is the only suitable noise descriptor for comparing the noise impact of a new noise source with that of other noise sources in the community. Some of the reasons for this result are discussed in this report.

It is important to differentiate between two different contexts in which noise descriptors are used; noise impact assessment and noise source definition. This report deals with the former, development of a way to describe the impact of maglev noise on the community. The metric introduced above, the Ldn, is the appropriate noise descriptor general enough to accommodate all kinds of noise sources, including those with various magnitudes, durations, and times of day. An example of the other context is the need for a descriptor of the noise associated with a single passby of the maglev vehicle. In that case, the descriptor must provide information on characteristics of a single noise source apart from the general noise environment, for example, noise level vs. speed. This comparison is often made in terms of the maximum A-weighted sound level, Lmax, during a passby. Lmax is used in describing the magnitude of noise from a single event and for comparing the effectiveness of various mitigation measures.

The background for considering environmental noise criteria for maglev is discussed in the next subsection.

1.2 Basis for Criteria

No directly applicable research on community reaction to maglev noise has been published to date, and none was performed under this contract. However, there is a general speculation that the rapid onset rates of noise associated with the proximity of fast-moving vehicles to residences could increase annoyance compared with other transportation vehicles. In fact, measured time history signatures of the TR 07 show fast rise times for nearby receivers. However, there is a lack of data for community reaction to intermittent noise events with brief, high level bursts of noise. The U.S. Air Force has been actively working to develop noise criteria for such cases, directly related to military training routes, based on extrapolations of best available data.[1] This study relies on the similarity of high speed maglev time histories and sound spectra with low-flying aircraft for which some data are available from military training routes. An underlying weakness of such a comparison may be the fundamental difference in the orientation of the vehicle with respect to the receiver; aircraft sound blankets an area from an overhead flight path, while maglev noise emanates from a linear source subject to ground effects near the earth surface. A further unknown in comparing maglev noise with aircraft noise is the psychological effect relating people's startle reaction from sudden noise events to fear of accidents*, whereas if the source is recognized as maglev, the public may be more confident that it is a vehicle constrained to a prescribed track.

Section 2 includes a description of the expected noise characteristics of a high speed maglev system and compares the time history plots from the TransRapid 07 with those of aircraft overflights. The onset rates (how fast the noise levels increase in time) of low-flying jet aircraft are found to be nearly the same as the high speed runs of TR 07, suggesting that corrections proposed for military training routes to account for startle may be applicable to maglev under certain conditions.

The proposed noise descriptor and criteria are described in Section 3. Ldn provides a reasonable basis for describing the cumulative effect of maglev passbys, but an adjustment to account for startle is needed. A set of criteria based on the contribution of maglev noise to the ambient Ldn is described. Section 4 includes an example of applying the criteria for estimating noise impact using the proposed criteria.

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* A low-flying aircraft may be perceived as an unusual event, signalling an impending disaster.

2. NOISE CHARACTERISTICS OF HIGH SPEED MAGLEV

People in the U.S. have not been exposed to noise from very fast moving surface transportation sources on a daily basis. Therefore, any criteria based on expected reaction will have to be drawn from the similarities of noise characteristics of maglev systems and aircraft for which criteria have been, or are being, established. Where similarities are demonstrated, the assumption is made that the community reactions will be the same. However, because no data are available directly applicable to people's reaction to noise from this new source, a conservative approach is taken in adopting criteria.

2.1 Expected Configuration

This section gives a brief overview of the kind of system envisioned for a future high speed maglev operation.

2.1.1 Guideway

For safety reasons, a new maglev transportation system is expected to be on exclusive guideway. Consequently, the running surface will be separated from the ground surface, typically 5 to 10 meters above grade. Since a typical two-story house is 8 meters high, this means that a maglev train can be thought of as operating along the top of roofs and sometimes at treetop height in suburban residential areas. The consequence of this configuration for noise propagation is that the first and second rows of houses abutting maglev rights-of-way will have direct line of sight to the noise source, but that homes beyond the second row may have the benefit of shielding. Such a configuration differs from the noise propagation path of an aircraft directly overhead which radiate downward to whole residential areas, or from highways and at-grade railroads where the noise propagation path closely follows the ground and is strongly affected by ground effects and terrain features.

2.1.2 Vehicle Consist and Headways

The ultimate configuration of the U.S. maglev system has not been established. During the current system concept studies various alternatives are being developed to carry 4000 to 12000 passengers per hour each way. The system could carry this many passengers with either long trains or short trains, with different headways. Some planners favor frequent two-car trains in order to provide maximum flexibility in service. These trains would be approximately 50 meters long and would operate at extremely short (60 second to 120 second) headways during peak periods. Other concepts include 8- and 10-car trains operating with greater headways.

2.1.3 Power and Speed

Maximum speeds are proposed to be very high, up to 500 km/hr between cities, although lower speeds may be utilized in urban areas. Propulsion would be electro-magnetic as is the levitation.

2.2 Passby Noise Signatures

The presence of a high speed maglev system in close proximity to homes may result in a new noise unlike any other existing sources of community noise. This section discusses the implications of these noise events on the potential for startle due to the sudden approach of a very loud event.

2.2.1 Time History Characteristics of a High Speed Maglev Passby

High speed maglev passbys are characterized by high noise levels and brief durations. Maximum noise levels at 25 meters from the guideway range from 77 dBA at 160 km/hr to 98 dBA at 435 km/hr for the TransRapid TR 07, as shown in Figure 1. Durations of the noise event depend on the length of the train and the distance of the receiver from the guideway, but for the two-car TR 07 at 435 km/hr shown in Figure 1, it takes only 3 seconds for the sound to rise and fall to 20 dB of the peak. Figure 1 also shows asymmetry in the time history which is characteristic of a fast-moving vehicle; the noise level rises faster than it falls. The onset rate** for the 435 km/hr signature is 21 dB per second, while the rate of decay is about 10 dB per second. This asymmetry is due to a number of effects related to the speed of the vehicle, including Doppler effect, convective augmentation and sound sourcedirectivity.

**Onset rate is the average rate of change of increasing sound pressure level during a single noise event.

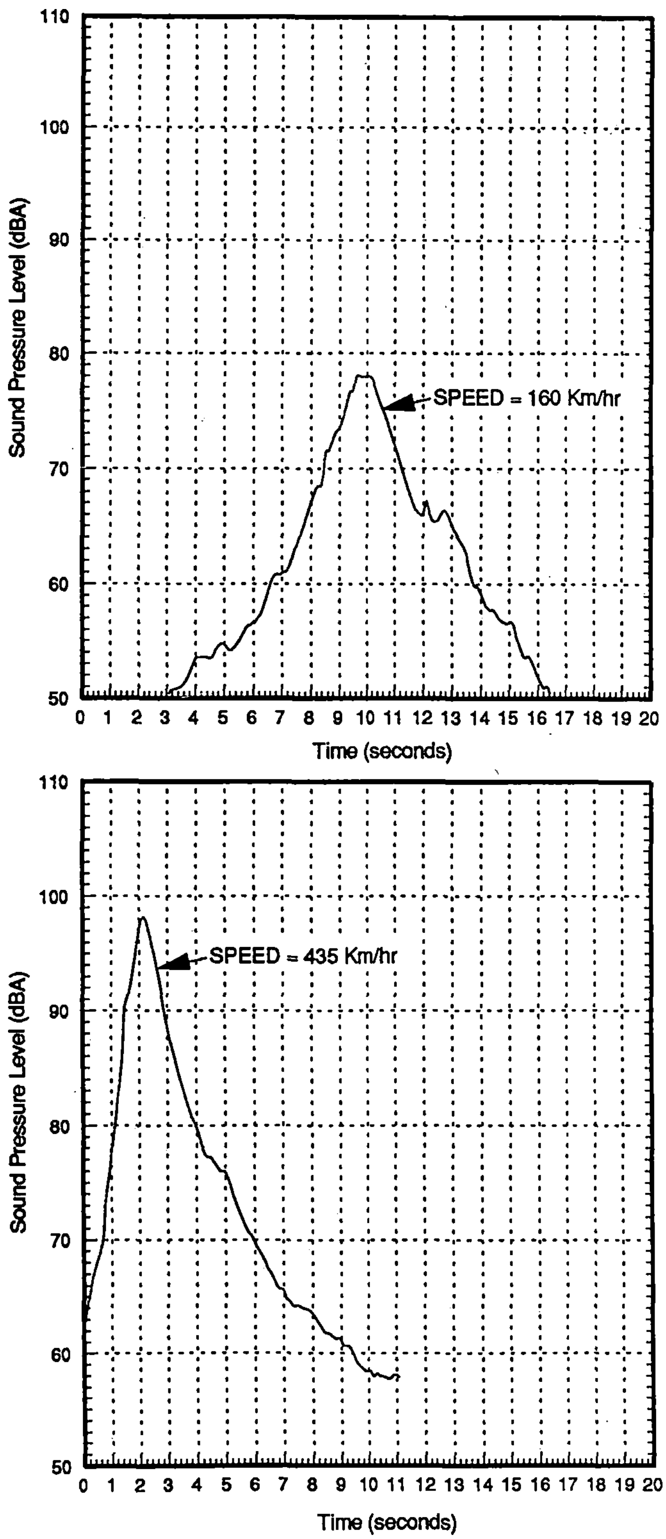


Figure 1. Time History of A-weighted Sound Levels of Maglev at 25 meters[2]

The onset rate is related to the rate of approach of a moving vehicle. More correctly, it is related to the rate at which the vector distance between the sound sources and the receiver is halved. Both speed and distance figure into the process. Measured onset rates for passbys of TR 07 measured by TUV Rheinland are shown plotted against the ratio of speed to distance in Figure 2. This plot shows how onset rate varies with the rate of change of angle between the train and the receiver. It can be seen that onset rate:

- changes directly as speed for a given distance,
- changes inversely as distance for a given speed.

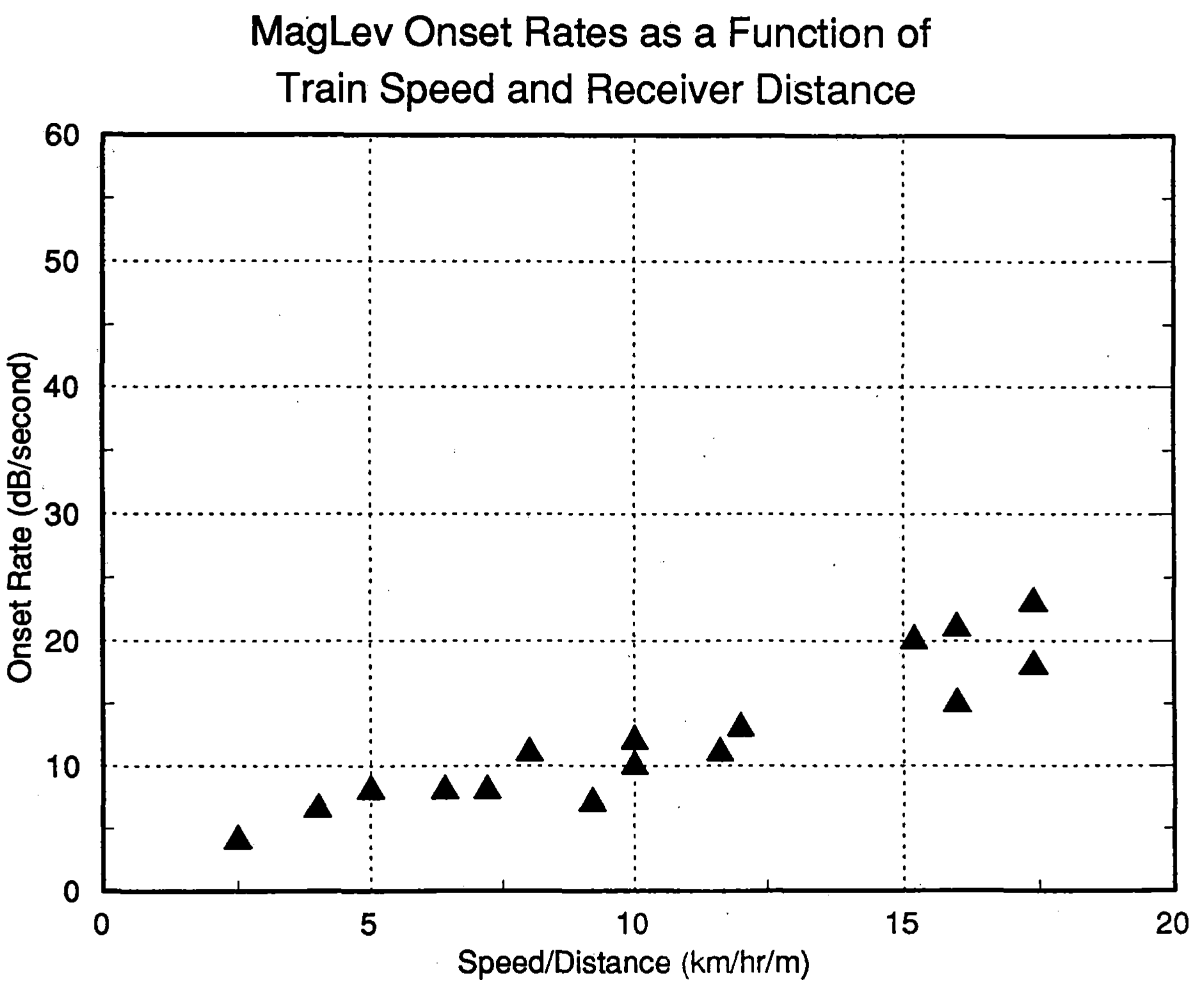


Figure 2. Measured Maglev (TR 07) Onset Rates as Function of Speed and Distance

The maglev time history signatures in Figure 1 are similar in shape to those shown in Reference 1 for individual flyovers of jet aircraft at low altitudes which are known to cause startle (Figure 3). For example, the onset rate of the low-flying B-1B shown in the figure is 15 dB per second and the B-52H is 10 dB per second for aircraft on military training routes. U.S. Air Force is considering special prediction metrics to take account of the increased annoyance response of communities due to startle.

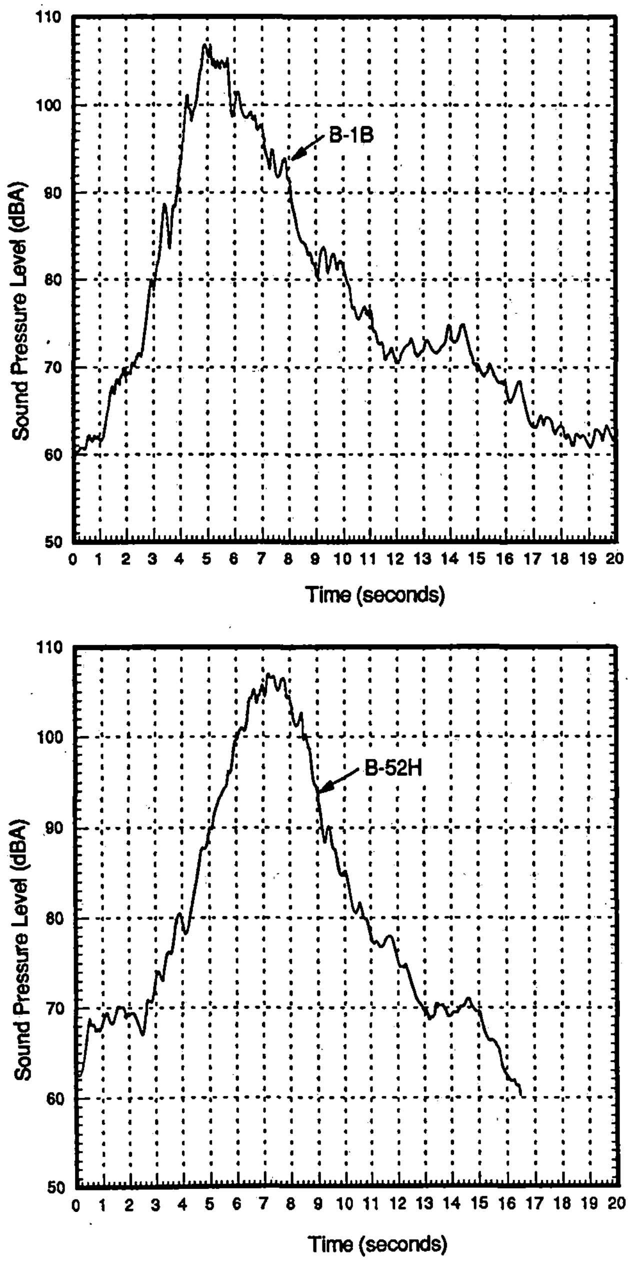


Figure 3. Time Histories of Low Altitude Aircraft Overflights (Ref. 1)

2.2.2 Annoyance Research Related to Onset Rate

Researchers report that sounds of approaching vehicles with signatures like these carry a sense of convergence and cause greater annoyance than receding sounds, perhaps from an increase in anxiety on the part of the receiver.[3] Moreover, sounds with fast rise time can be classified as impulsive in nature which are more annoying than noise with less rapid variations or steady noise with the same maximum noise level (see Ref. 1 for a summary). Various adjustments have been proposed to account for the increased impact of fast-rising sound events, but the bulk of evidence to date has focused on a 5 dB correction for "fast-rising" events. This means that for events with the same sound exposure level, people would judge an event with an abrupt change 5 dB noisier than one with a more gradual change even if the two sounds carry the same sound energy. Two such signals are shown in Figure 4; they both contain the same sound energy, but the second signal would be judged 5 dB noisier.

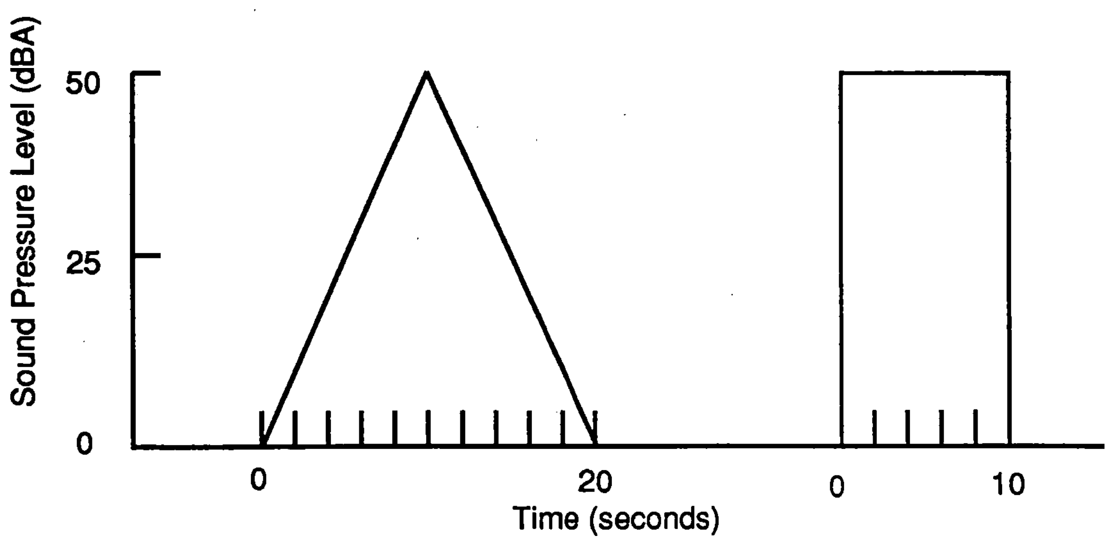


Figure 4. Single Events with Same Energy but with Different Onset Rates

These and other ongoing research findings have resulted in a proposed onset rate adjustment for assessing the potential noise impacts associated with military training routes by the U.S. Air Force. Although subject to revision and under current discussion,[4] the recommended adjustment to sound exposure level (SEL) of a single event is shown in Figure 5 (from Reference 1). The onset rate adjustment starts at 15 dB per second and reaches a maximum of 5 dB for onset rates greater than 30 dB per second. Between 15 dB per second and 30 dB per second, the adjustment follows the relation:

$$\text{Onset Rate Adjustment} = 16.6 \log_{10} (\text{onset rate}/15).$$

This adjustment is applied only to those single events where the maximum level exceeds the ambient level by 15 dBA, thereby eliminating from consideration events considered to have an insignificant effect.

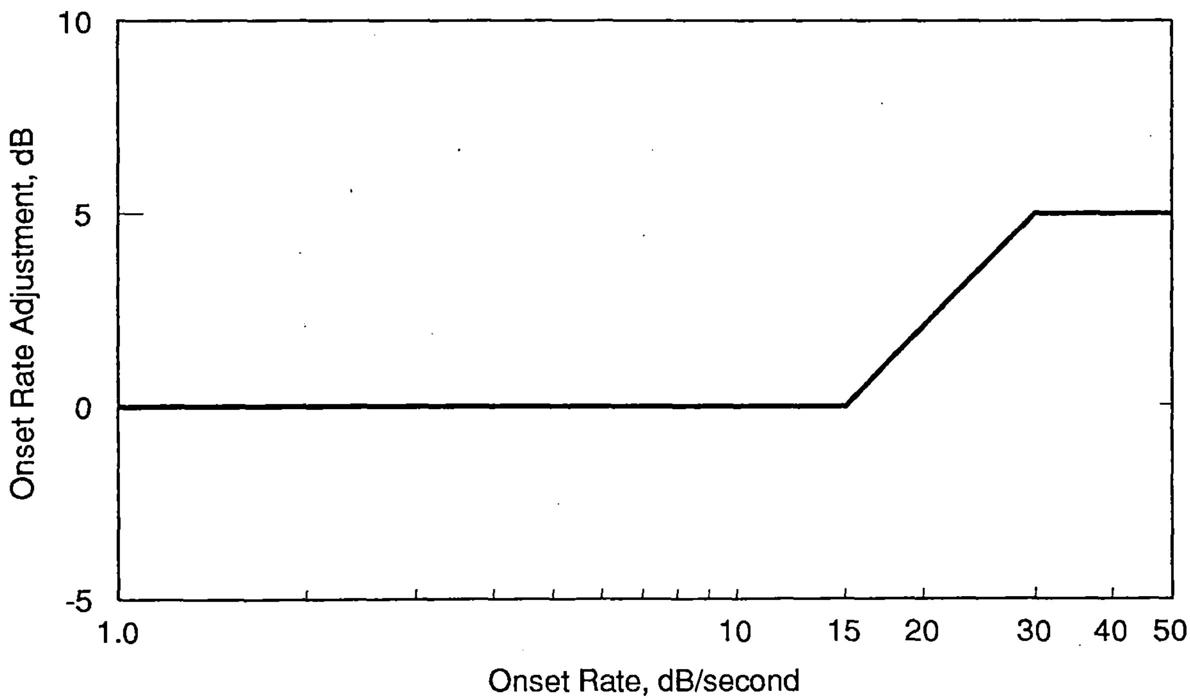


Figure 5. Proposed USAF Adjustment to SEL for Onset Rate

2.3 Noise Spectra

It has been demonstrated that sounds with rapid onset rates have about 5 dB more impact than those with gradual increases, and that high speed maglev noise signatures have rapid onset rates under some conditions. The next question has to do with judged noisiness of various frequency spectra, and to determine if high speed maglev is likely to have sound qualities judged to be more, or less annoying than other transportation sources.

2.3.1 Spectral Characteristics of a High Speed Maglev Passby

Noise from high speed maglev passbys is generally characterized by a broad band spectrum of frequencies over the sub-audible and audible range. In the first report of this series, the noise from high speed maglev trains is shown to be made up of many sources, including propulsion, mechanical/structural and aeroacoustic. Each type of source dominates a portion of the noise spectrum, but with a blending that makes it difficult to sort them out. A typical example is shown in Figure 6, where the lowest frequencies are associated with mechanical/structural radiation and the mid frequencies are associated with aeroacoustic sources. The spectra do not exhibit unusual characteristics, although pure tones can occur in maglev from mechanical sources (at the magnetic pole passing frequency) and from aerodynamic sources (periodic vortex shedding) (For example, see Figure 7).

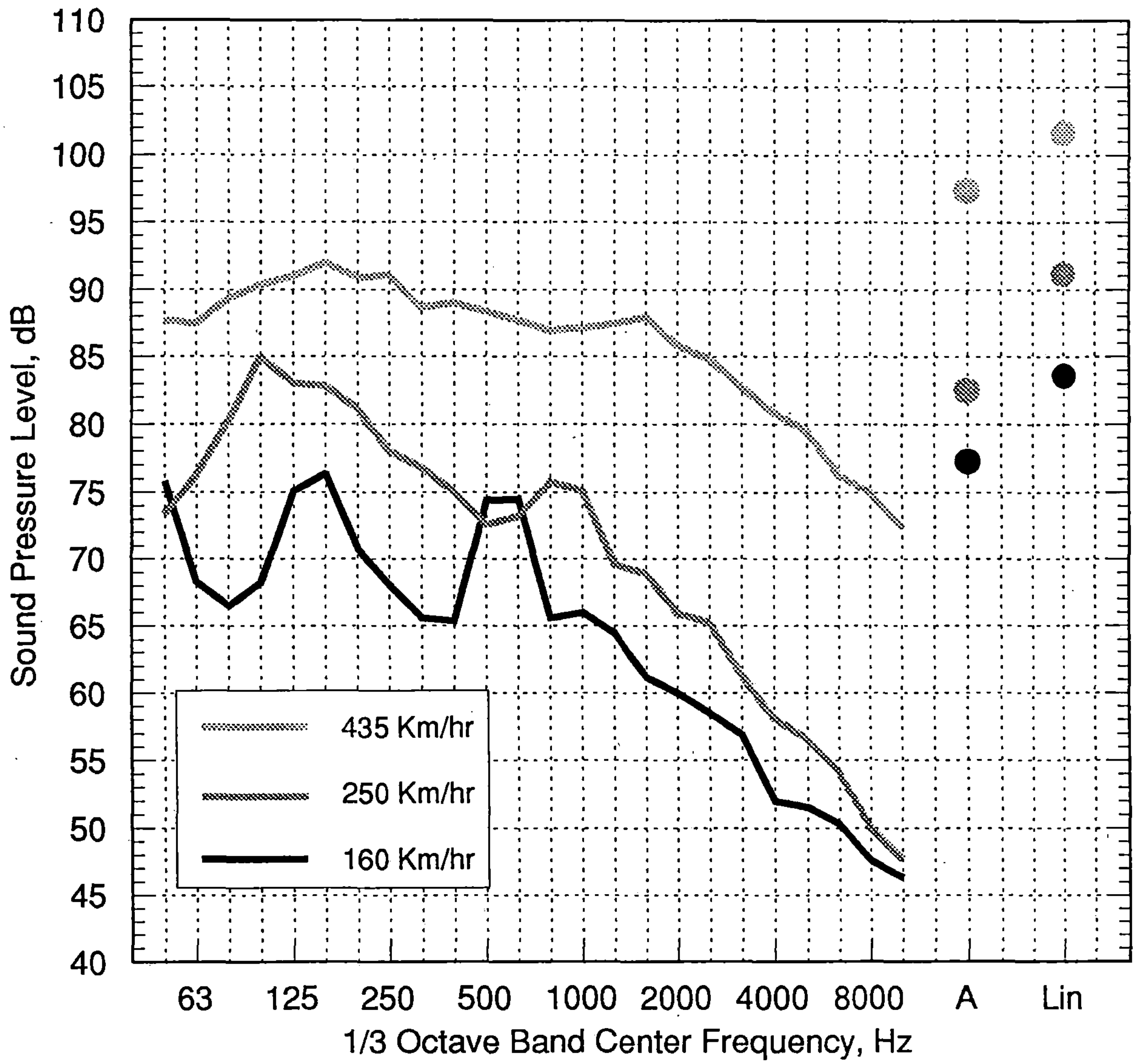


Figure 6. Noise Spectra of Maglev Passbys (Ref. 2)

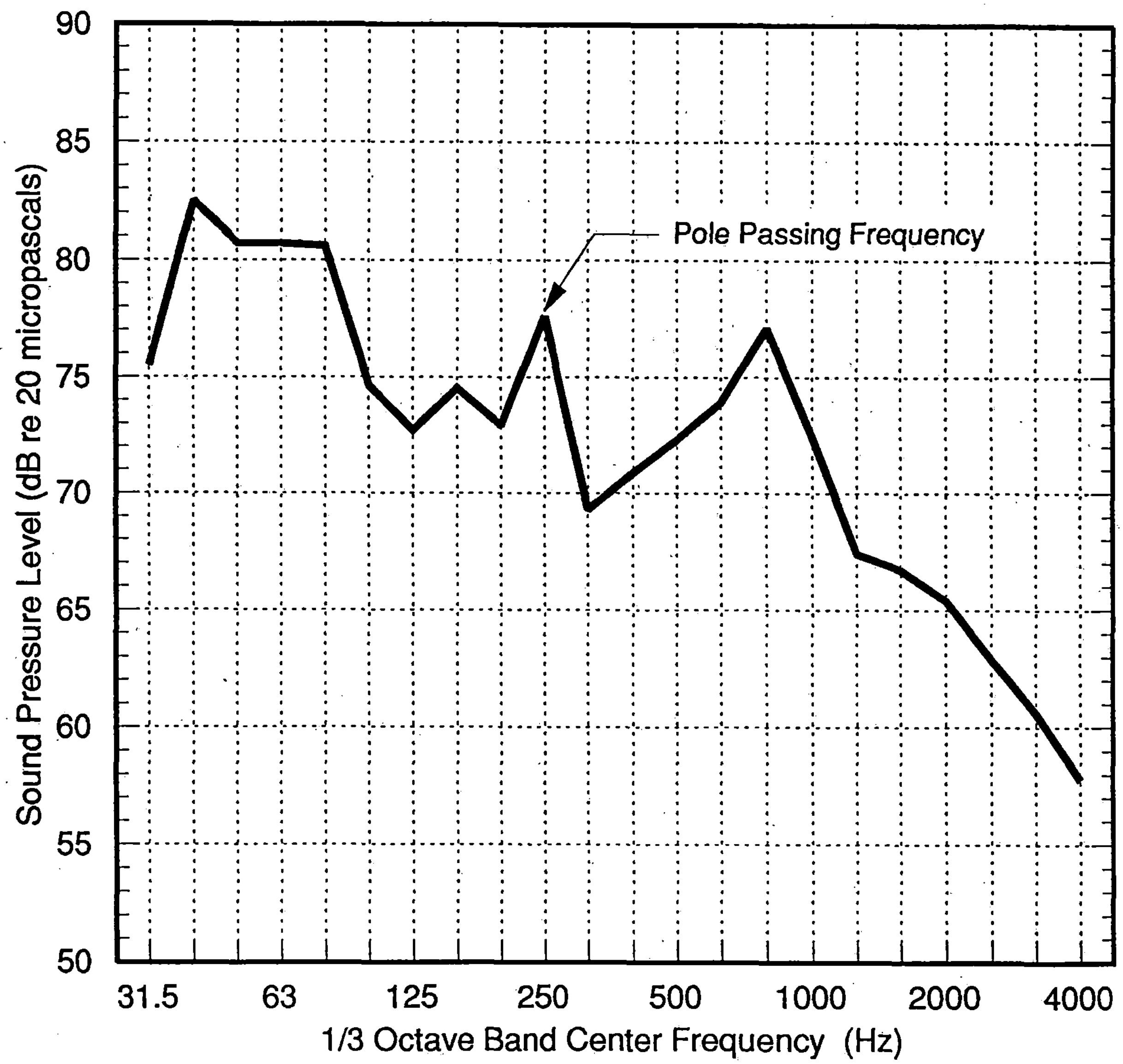


Figure 7. Spectrum of TR 07 at 68 m/s Showing Pure Tone (HMMH measurement)

2.3.2 Annoyance Research Related to Sound Spectra

Researchers have found that sounds with unusual frequency composition are judged to be noisier than those with broad-band sound characteristics, even when both sounds have the same measured sound exposure level. Noise with a pure tone content is an example of a particularly annoying sound, with a judged noisiness of 5 dB greater than sounds without a tone.[5] A great deal of effort has gone into in developing and testing noise descriptors incorporating tone corrections, especially for estimating annoyance from various types of aircraft. However, for a number of reasons, not the least of which is the availability of measurement instrumentation, the A-weighted sound level has evolved as the metric of choice for describing all types of environmental noise. Since no tone correction is incorporated in the A-weighting, any adjustment must be added to the sound level to account for the increased annoyance from tonal sounds. One example of such a correction is in the noise specifications for rapid transit vehicles; the American Public Transit Association Guidelines recommends a 3 dB penalty for presence of pure tones.[6] The position of the pure tone in the frequency spectrum may be important in the degree of increased annoyance; a very low frequency or a very high frequency tone may be less annoying than one located where human hearing is most sensitive. Consequently, when a penalty for pure tone is applied, frequency limits should be, but seldom are, imposed.

2.4 Cumulative Effects

The third factor that figures into people's reaction to noise is the duration of a single event and the cumulative duration of a number of separate events. Two questions are often asked: "Are people more annoyed by short noisy events or long quieter events?" and "Are people more annoyed by a long event, or by a series of shorter events with the same cumulative sound energy?" In relation to maglev, those questions concern the relative annoyance from long vs. short trains. For answers, psychoacoustical researchers point to laboratory data that indicate people judge equally noise events that have the same sound energy. This implies that loud, brief events are judged to be equivalent to longer, quieter events provided they have the same sound energy content. This is the basis for the equal-energy concept which underlies community noise response models. The concept is extended to multiple events by adding the energy of each event to develop a total. This simplification is especially attractive for computational purposes because the individual noise energies for different noise sources, or for different segments of time, can be easily combined to determine the total energy. Consequently, a new noise source can be compared to the existing ambient or to other sources using the same descriptor, and its contribution to the cumulative sound level can be easily determined.

Community response is related to the total noise energy in a specified time period. This finding, which is discussed in Section 3.1, is the basis for the acceptance of Leq and Ldn descriptors for community noise assessment. Leq is the single number "equivalent sound level," a steady noise level that contains the same acoustical energy as the actual time-varying noise pattern over the same time period. A major advantage of the equivalent sound level is the quality of being able to add Leq's from several different sources to determine a total Leq, provided the computation covers identical time periods, for example, one hour. The hourly Leq is a commonly-used descriptor for environmental noise; peak traffic hour Leq is used in highway noise computation models. For environmental noise descriptions it is understood that A-weighted sound levels are used for Leq.

Over the period of one hour, the Leq has been shown to correlate quite well with people's judgement of noise during that period. However, community response and public opinion surveys reveal that the same noise environment is considered more disturbing during the nighttime than during daytime. Lower nighttime noise levels are desirable for better sleep and relaxation conditions, but in addition, the ambient noise in most residential communities decreases by 10 dB or more at night. Consequently, any exterior noise source is likely to be more disturbing at night. To account for this increased potential for nighttime disturbance, the environmental noise descriptor, called the day-night sound level, Ldn, is used. Ldn is the Leq over a 24-hour period, but with a weighting factor of 10 dB applied to noises that occur during the nighttime hours of 10 p.m. to 7 a.m. Again, A-weighted sound level is assumed for the Ldn.

The cumulative effect of maglev noise on the environment, therefore, depends on the sound energy of each passby, the number of passbys, and the time of day of those passbys. For a description of the noise during peak hour of operations, the total Leq at a given location is the Leq of one operation at that location plus 10 times the logarithm of the number of operations in that hour:

$$Leq_{hour} = Leq_{passby} + 10 \log_{10} N \quad \text{dBA},$$

where Leq_{hour} is the total equivalent sound level in an hour,
Leq_{passby} is the contribution to the hourly Leq of one passby, and
N is the number of passbys with the same sound energy in the hour.

A more practical way of expressing the cumulative noise level during a period of time involves the use of another time-integrated measure, the Sound Exposure Level (SEL). SEL is the total sound energy of one event normalized to a one-second time period, the fundamental time unit used in the MKS system. Determining the hourly Leq from a number of different sources is easy when the SEL of each source is known at a given location:

$$Leq_{hour} = \text{Energy Sum of all SEL's} - 10 \log_{10} 3{,}600$$

$$= \text{Energy Sum of all SEL's} - 35.6 \qquad \text{dBA},$$

where Energy Sum means decibel addition of the SEL's,
and the 3,600 comes from the number of seconds in an hour.

One way of interpreting this expression is that the total sound energy is expressed in the first term, and the time period in seconds over which the sound energy is considered is expressed by the second term. This expression is used in computation methods because SEL's have been tabulated usually at a reference distance, such as 25 m, for various sources, such as automobiles, trucks, locomotives, train coaches, aircraft, etc., and the contribution of each can be added to determine the total energy in an hour.

SEL's from maglev operations can also be measured. For example, Figure 8 shows the SEL's measured on TR 07 normalized to a single vehicle of 25 m length. The original data came from TUV Rheinland's measurements of the 2-car TR 07 "train" with the rough assumption that sound energy is emitted equally from each car.*** The relationship between normalized SEL and speed, in Km/hr, is given by:

$$\text{Normalized SEL} = 79 + 40 \log(\text{speed}/200), \quad \text{dBA}.$$

The SEL at a reference distance for a train of maglev vehicles can be estimated from the following expression:

$$SEL_{train} = SEL_{car} + 10 \log_{10} N \qquad \text{dBA},$$

where SEL_{car} = SEL of a single car at given speed at the reference distance of 25 m

*** Not necessarily a valid assumption for all speeds; the leading car may actually radiate more aeroacoustic energy at high speeds than the trailer due to separation and reattachment of the boundary layer near the nose.

(Figure 8), and N = number of cars in the train.

The Leq for an hour of operations can be determined from the SEL, and the Ldn can then be determined using the expressions described previously. This is the building block used in the application example described in Section 4.

Note that although the SEL of each train depends on the length of the train, Ldn and Leq_{hour} are insensitive to the length of trains. It does not matter whether there are few long trains or many short trains carrying the passengers. All that counts is the number of cars passing a location during the given time period.

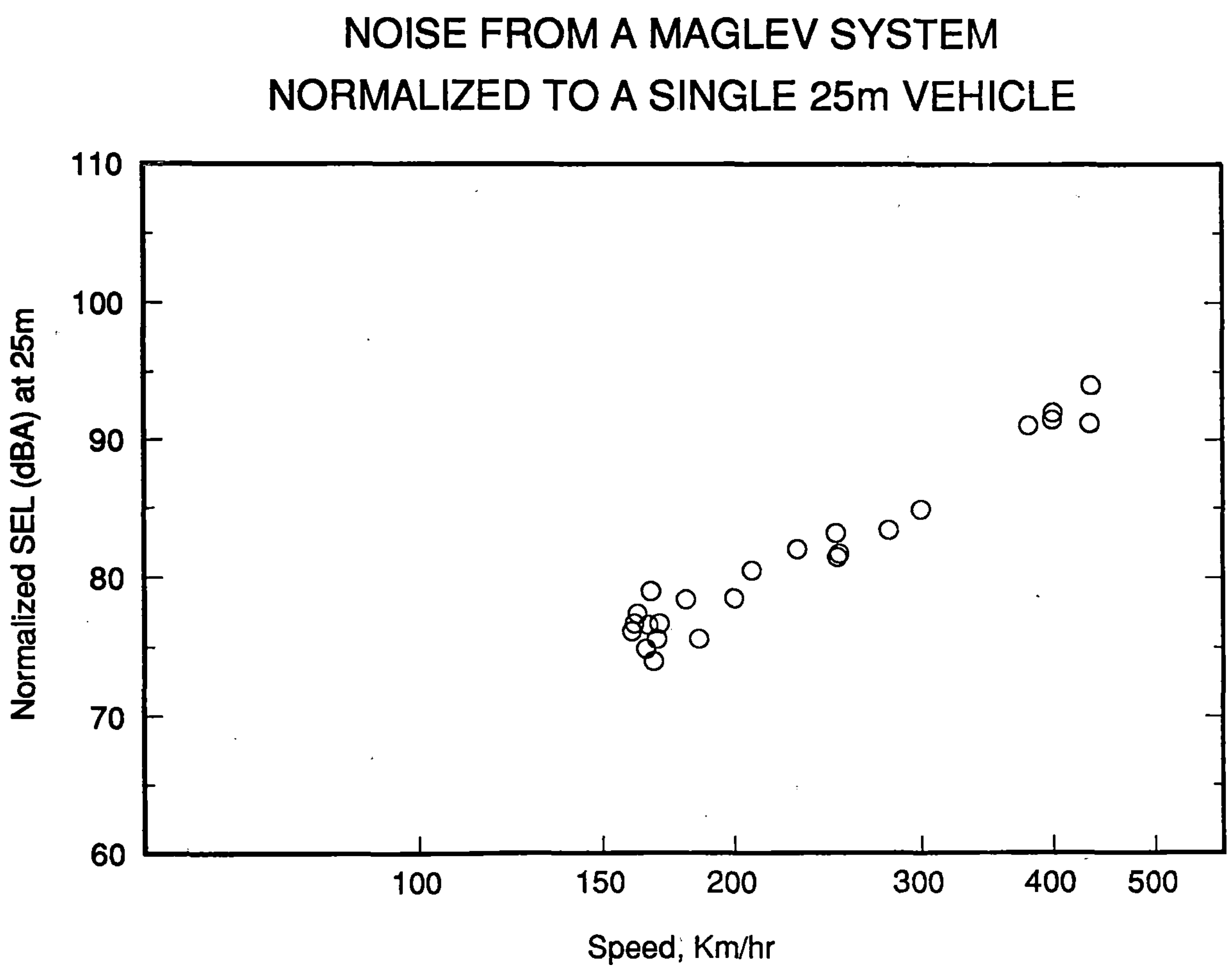


Figure 8. Normalized Sound Exposure Level of TR 07 at Distance of 25 m.

3. PROPOSED NOISE CRITERIA FOR HIGH SPEED MAGLEV SYSTEM

This section presents a proposed set of criteria to be used in evaluating noise impact from high speed maglev operations. These criteria are based on those included in the Federal Transit Administration's "Draft Guidance Manual for Transit Noise and Vibration Impact Assessment."[7] The criterion for the onset of Impact varies according to the ambient noise and predicted maglev noise levels and is determined by the threshold at which the percentage of people highly annoyed by maglev noise would start to become measurable. The corresponding criterion for Severe Impact similarly varies according to the ambient noise level as well as the maglev noise level, but is determined by a higher, more significant percentage of people highly annoyed by maglev noise. Background material on the development of the criteria from Reference 7 are summarized in this Section, and guidelines for the application of the criteria are included in Section 4.

3.1 Noise Descriptor

The noise descriptor adopted for use in the proposed criteria is the day-night sound level (Ldn). As described in Section 2, the Ldn is a measure of a receiver's cumulative noise exposure from all events over a full 24 hours, with all nighttime events given an extra weighting of 10 dB. Ldn is the metric of choice of most Federal agencies with noise standards (Department of Housing and Urban Development, Federal Aviation Administration, Environmental Protection Agency) and also has a wide acceptance internationally.

Ldn can be thought of as a unit in which complex environmental noise situations can be expressed in a single number. It includes:

- Spectral content corresponding to the way in which humans interpret sound, according to the A-weighting curve;
- Equal energy considerations in that the trade-off between sound level and duration corresponds to 3 dB per doubling of duration; and
- Time of day sensitivity in that nighttime events receive an extra weighting of 10 dB.

Furthermore, and perhaps most important, Ldn correlates well with the results of attitudinal surveys of residential noise impact. This conclusion resulted from a number of research and synthesis studies relating to community noise of all types supported by the U.S. Environmental Protection Agency (EPA) in the 1970's. In a large number of community attitudinal surveys, transportation noise has been ranked among the most significant causes of community dissatisfaction. A synthesis of many such surveys on annoyance appears in Figure 9, where the percentage of people who are "highly annoyed" by their neighborhood noise is plotted against the Ldn of their neighborhoods.[8,9] The term "highly annoyed" is deliberately chosen; these are the people who in response to surveys placed annoyance from noise at or near the top of their neighborhood concerns. The dominating sources of noise in these surveys included aircraft, railroad, transit and street traffic. Based on the results of these data, Schultz proposed the universal transportation noise response curve relating percent highly annoyed to Ldn, as shown in the figure. It is assumed that the results of these surveys are source-independent, and that people would be highly annoyed by any transportation source that would cause noise at the corresponding levels. The equation for the least-squares fit to the annoyance data is:[10]

$$\%HA = 0.8553\ Ldn - 0.0401\ Ldn^2 + 0.00047\ Ldn^3.$$

Because it describes expected community annoyance to noise from transportation sources, this equation is used to develop the criteria curves in the next section.

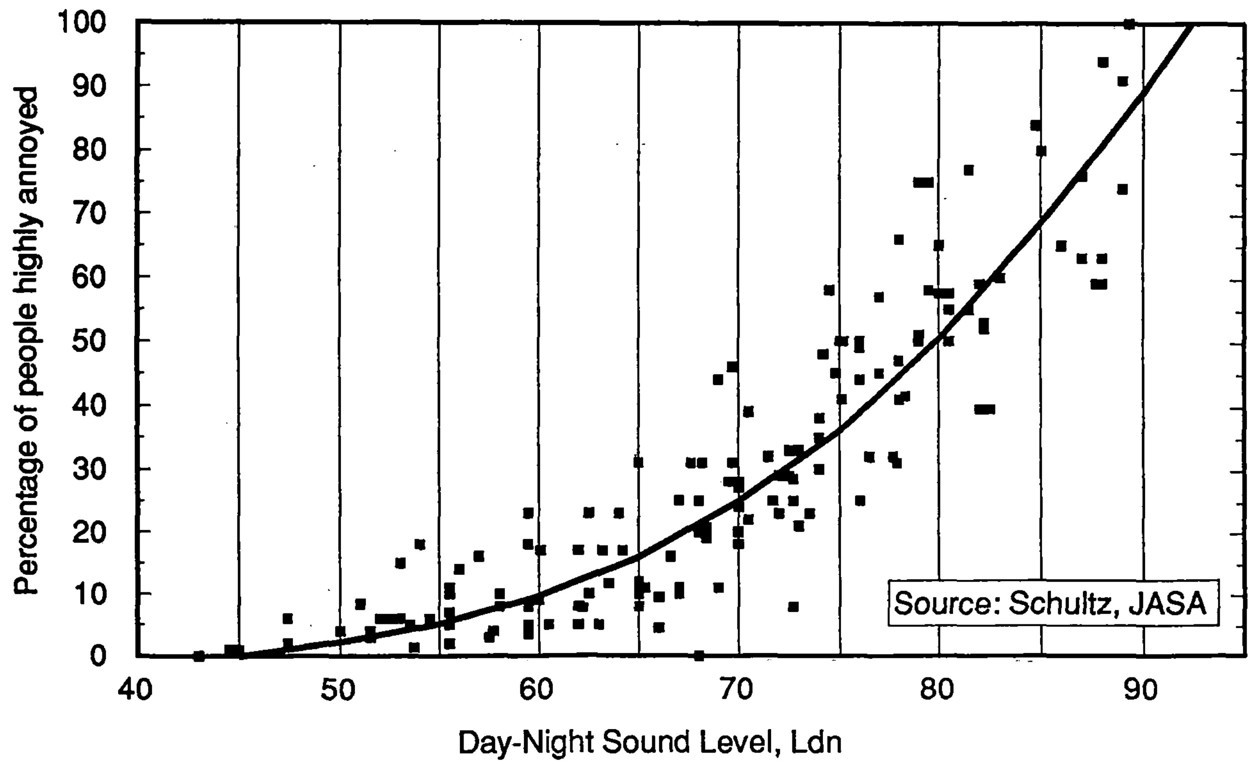


Figure 9. Community Annoyance Due to Noise

As discussed in Section 2, there is considerable evidence that an adjustment is required for sound signatures with rapid onset rates. Based on the foregoing discussion of Ldn and the need for an adjustment for onset rate, it is recommended that an "onset-rate adjusted day-night sound level" be used to assess noise impact from maglev operations. This unit is the Ldn contribution from maglev operations as computed from the SEL's of individual passbys, except that an adjustment is made to the SEL's for passbys with rapid onset rates. A simple adjustment is proposed for ease in application and for purposes of being conservative;

add 5 dB to the SEL for onset rates of 15 dB per second or more.

This adjustment for maglev differs from that of the USAF, where the adjustment gradually reaches 5 dB between onset rates from 15 dB/sec to 30 dB/sec.

Figure 10 shows the relationship of speed and distance to define locations where the onset rate exceeds 15 dB per second for a maglev train. This curve was determined using a "Single Vehicle Passby Program," developed by HMMH for the National Park Service.[11] This program accounts for divergence, directivity, convective augmentation, ground effect, atmospheric absorption and emission level (spectra) as a function of speed. TR 07 data measured by TUV Rheinland and HMMH were used to obtain the relationship shown in the figure.

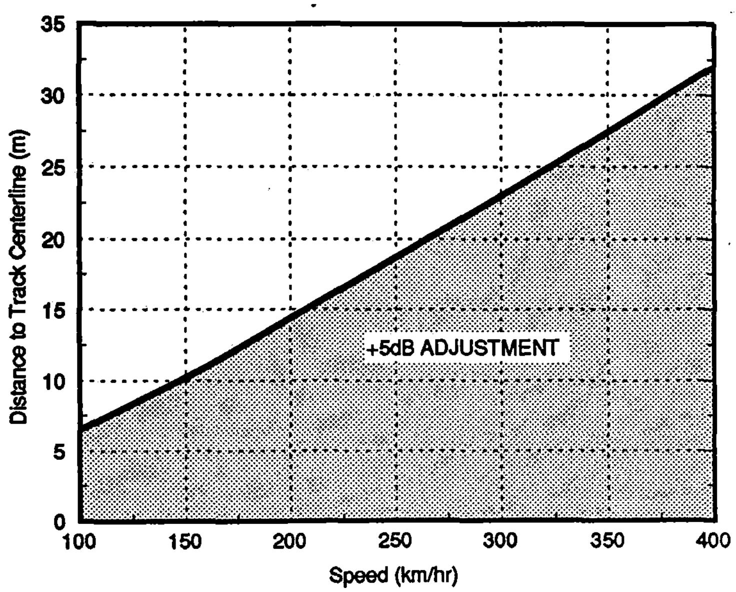


Figure 10. Proposed Onset Rate Adjustment to SEL's from Maglev

3.2 Noise Criteria

The noise impact criteria for maglev operations are shown graphically in Figure 11. These criteria are based on comparison of the existing noise levels and future noise levels of the maglev operations. These criteria are identical to those proposed by the Federal Transit Administration for assessing noise impact from urban transit operations (Reference 7), with the single difference that the "onset-rate adjusted Ldn" is used for maglev operations.

The noise criteria and descriptors depend on land use, designated either Category 1, Category 2 or Category 3:

> Category 1 includes tracts of land where quiet is an essential element in their intended purpose, such as nationally significant historic sites or outdoor concert pavilion.
>
> Category 2 includes residences and buildings where people sleep,
>
> Category 3 includes institutional land uses with primarily daytime and evening use such as schools, churches and active parks.

For Category 2 land use where nighttime sensitivity is a factor, the noise criteria use Ldn. For Category 1 and 3 land uses involving primarily daytime activities, the impact is evaluated in terms of the Leq for the noisiest hour of maglev-related activity during which human activities occur at a noise-sensitive location. The latter is referred to as "peak hour Leq." Because the Ldn and daytime peak-hour Leq have similar values for typical noise environments, they are used interchangeably to evaluate noise impact for Category 1 and Category 2 sites. However, because Category 3 sites are less sensitive, the criteria allow the maglev noise to be 5 decibels greater than for Category 1 and Category 2 sites.

The noise impact criteria are defined by two curves which allow increasing project noise levels as ambient noise increases up to a point, beyond which impact is determined based on maglev noise alone. Below the lower curve in Figure 11, a maglev system is considered to have no noise impact since, on the average, the introduction of the system will result in an insignificant increase in the number of people highly annoyed by the new noise. The curve defining the onset of noise impact stops increasing at 65 dB for Category 1 and 2 land use, a standard limit for an acceptable living environment defined by a number of Federal agencies. Maglev noise above the upper curve is considered to cause Severe Impact since a significant percentage of people would be highly annoyed by the new noise.

This curve flattens out at 75 dB for Category 1 and 2 land use, a level associated with an unacceptable living environment. As indicated by the right-hand scale on Figure 11, the project noise criteria are 5 decibels higher for Category 3 land use.

Between the two curves the proposed project is judged to have an impact, though not severe. The change in the cumulative noise level is noticeable to most people, but may not be sufficient to cause strong, adverse reactions from the community. In this transitional area, other project-specific factors must be considered to determine the magnitude of the impact and the need for mitigation, such as the predicted level of increase over existing noise levels and the types and numbers of noise-sensitive land uses affected.

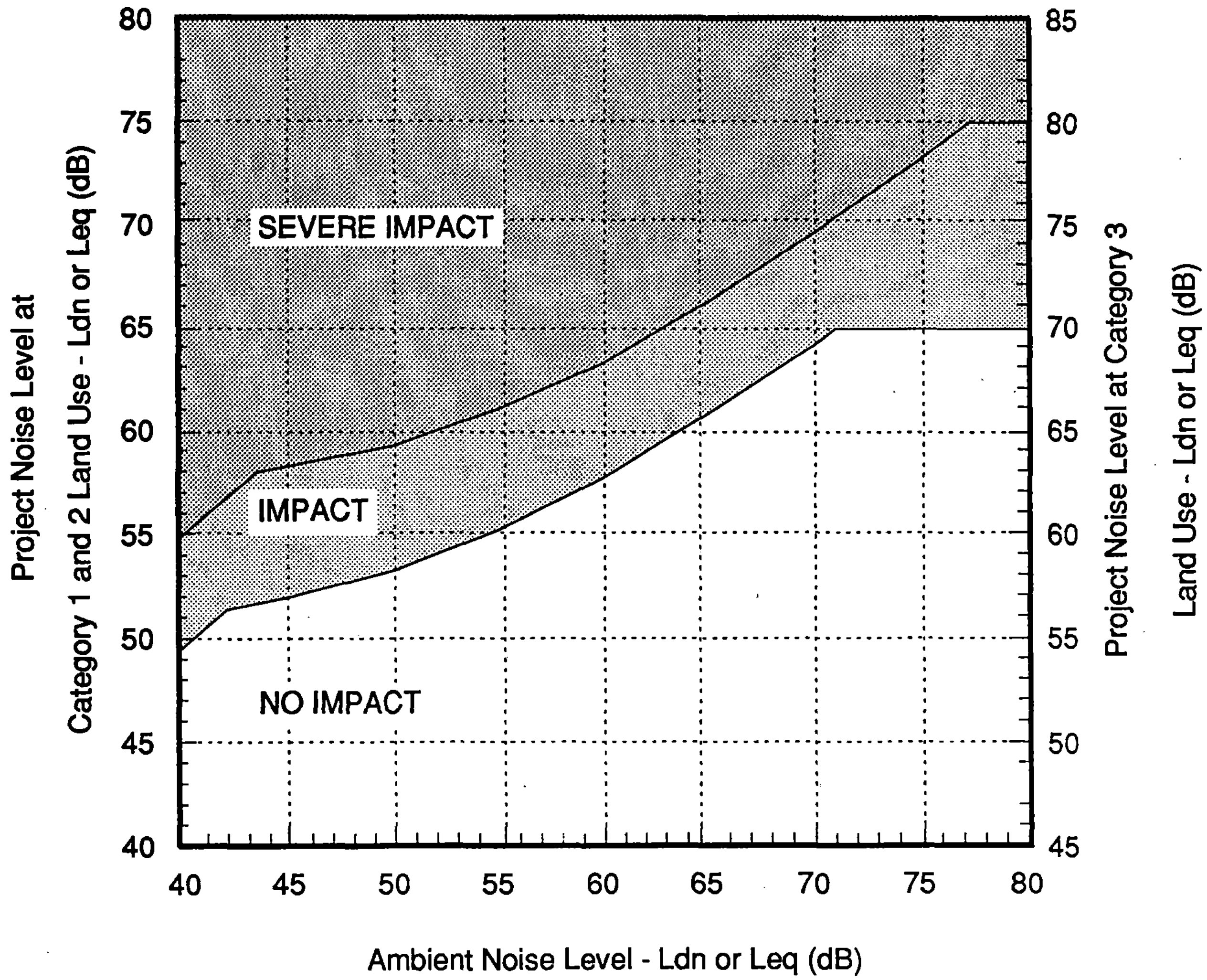


Figure 11. Proposed Noise Impact Criteria

3.3 BACKGROUND

The noise criteria have been developed based on well-documented criteria and research into human response to community noise. The primary goals in developing the noise criteria were to ensure that the impact limits be firmly founded in scientific studies, be realistically based on noise levels associated with new transit projects, and represent a reasonable balance between community benefit and project costs. This section provides a summary of the background information found more completely in Reference 7.

3.3.1 Basis for Noise Impact Criteria Curves

The lower curve in Figure 11 representing the onset of Impact is based on the following considerations:

- The EPA finding that a community noise level of Ldn less than or equal to 55 dBA is "requisite to protect public health and welfare with an adequate margin of safety."[12]
- The conclusion by EPA and others that a 5 dB increase in Ldn or Leq is the minimum required for a change in community reaction. (See Reference 12 for a full discussion.)
- The research finding that there are very few people highly annoyed when the Ldn is 50 dBA, and that an increase in Ldn from 50 dBA to 55 dBA results in an average of 2% more people highly annoyed (see Figure 9).

Consequently, the change in noise level from an existing 50 dBA to 55 dBA caused by a project is assumed to be a minimal impact. Expressed another way, this is considered to be the lowest threshold where impact starts to occur. Moreover, the 2% increment represents the minimum measurable change in community reaction. Thus the curve's hinge point is placed at a project noise level of 53 dBA and ambient of 50 dBA, the combination of which yields 55 dBA. The remainder of the lower curve in Figure 11 was determined from the annoyance curve (Figure 9) by allowing a fixed 2% increase in annoyance at other levels of existing ambient noise. As cumulative noise increases, it takes a smaller and smaller increment to attain the same 2% increase in highly annoyed people. For example, while it takes a 5 dB noise increase to cause a 2% increase in highly annoyed people at an existing ambient noise level of 50 dB, an increase of only 1 dB causes the 2% increase of highly annoyed people at an existing ambient noise level of 70 dB.

The upper curve delineating the onset of Severe Impact was developed in a similar manner, except that it was based on a total noise level corresponding to a higher degree of impact. The Severe Noise Impact curve is based on the following considerations:

- The Department of Housing and Urban Development (HUD) in its environmental noise standards defines an Ldn of 65 as the onset of a normally unacceptable noise zone.[13] Moreover, the Federal Aviation Administration (FAA) considers that residential land uses are not compatible with noise environments where Ldn is greater than 65 dBA.[14]

- The common use of a 5 dBA increase in Ldn or Leq as the minimum required for a change in community reaction (Again, see Reference 12 for details).

- The research finding that the foregoing step represents a 6.5% increase in the number of people highly annoyed (see Figure 9).

Consequently, the increase in noise level from an existing 60 dBA to a cumulative level of 65 dBA caused by a maglev system represents a change from an acceptable noise environment to the threshold of an unacceptable noise environment. This is considered to be the level at which severe impact starts to occur. Moreover, the 6.5% increment represents the change in community reaction associated with severe impact. Thus the upper curve's hinge point is placed at a project noise level of 63 dBA and ambient of 60 dBA, the combination of which yields 65 dBA. The remainder of the upper curve in Figure 11 was determined from the annoyance curve (Figure 9) by fixing the 6.5% increase in annoyance at all ambient noise levels.

Both curves incorporate a maximum limit for the maglev noise in noise-sensitive areas. Independent of existing noise levels, Impact is considered to occur whenever the maglev Ldn exceeds 65 dBA and Severe Impact occurs whenever the maglev Ldn exceeds 75 dBA. These absolute limits are intended to restrict activity interference by maglev noise.

4. APPLICATION METHOD

4.1 Procedure for Noise Impact Assessment

The procedure for assessing impact is to determine the pre-project ambient noise level and the predicted maglev noise level at a given site, in terms of either Ldn or Leq as appropriate, and to plot these levels on Figure 11. The location of the plotted point in the three impact ranges is an indication of the severity of the impact.

The noise criteria are to be applied outside the building locations for residential land use and at the property line for parks and other significant outdoor use. However, for locations where land use activity is solely indoors, noise impact may be less significant if the outdoor-to-indoor reduction is greater than for typical buildings.

It is important to note that the criteria specify a comparison of future project noise with existing ambient noise and not with projections of future "no-build" noise levels (i.e. without the project). Furthermore, it should be emphasized that it is not necessary nor recommended that existing ambient noise levels be determined by measuring at every noise-sensitive location in the project area. Rather, the recommended approach is to characterize the noise environment for "clusters" of sites based on measurements at representative locations in the community. Guidelines for selecting representative receiver locations and determining ambient noise are provided in Reference 7.

The noise impact criteria are defined by the two curves delineating onset of Impact and Severe Impact. Below the lower curve in Figure 11, a proposed maglev system is considered to have no noise impact for any of the above land use categories. Maglev noise above the upper curve is considered to cause Severe Impact for all land use categories. Severe noise impacts are considered "significant" as this term is used in the National Environmental Policy Act (NEPA) and implementing regulations.

Between the two curves the proposed project is judged to have an impact, though not severe. In this range, other project-specific factors must be considered to determine the magnitude of the impact and the need for mitigation, such as the predicted level of increase over existing noise levels -- where the plotted points lie with respect to the upper curve -- and the types and numbers of noise-sensitive land uses affected. Whether the noise impact is determined "significant" in the context of NEPA will depend on these factors, as well as the ability to mitigate noise to more acceptable levels.

4.2 Example of Application of Criteria

For our example of noise impact from the introduction of maglev as it exists now without noise mitigation, we will look at the existing passenger train service provided in the Northeast Corridor between Boston and New York. The proposed criteria are based on Ldn which requires consideration of the noise from train passbys during daytime (7 am to 10 pm) and nighttime (10 pm to 7 am) hours separately. The example is based on a selected point along the route, a suburb of Boston. Residences in this area are located typically as close as 30 m from existing tracks. Urban or suburban residential areas with population density of 2,500 people per square kilometer are expected to have an existing ambient Ldn of 60 dBA (from Reference 12). With that number as the existing ambient, the proposed criteria show that Ldn's of 58 dBA and 63 dBA from a new source would cause "impact" and "severe impact," respectively (from Figure 11).

Current 1991 Northeast Corridor service between Boston and New York has a total of 16 day and 6 night trains passing through the suburbs of Boston. Assuming the same frequency and a similar level of service could be provided by 10 - car maglev trains with the same schedule, the normalized SEL from Figure 8 is converted to SEL for a 10-car train at a speed of 400 Km/hr using the SEL equation in Section 2.4, with the "onset rate adjustment" obtained for the appropriate speed from Figure 10. For a speed of 400 Km/hr, Figure 10 shows an addition of 5 dB for sites within 32 m of the guideway.

Ldn is subsequently obtained from spreading out the energy contained in 22 total events over 24 hours, but first adding 10 dB to each nighttime event (maglev passbys). The result is an Ldn of 71.5 dBA at 25 m. The line labeled "Boston suburb" in Figure 12 illustrates the distances from the guideway that would considered to be impacted using the proposed criteria. The noise propagation with distance over open terrain was taken from actual measurements at the TR 07 test track. The discontinuity in the Ldn line at 32 m occurs because that is the point at which the onset rate is expected to drop below 15 dB/sec (as shown in Figure 10). Impact would occur for any residence within 80 m of the guideway and severe impact would result for any residence within 40 m.

The method can be employed in reverse to determine the speed at which no impact will occur for a residential area. For example, if the nearest house was 30 m, the speed would have to be reduced to 267 Km/hr to fall into the "no impact" zone of Figure 11.

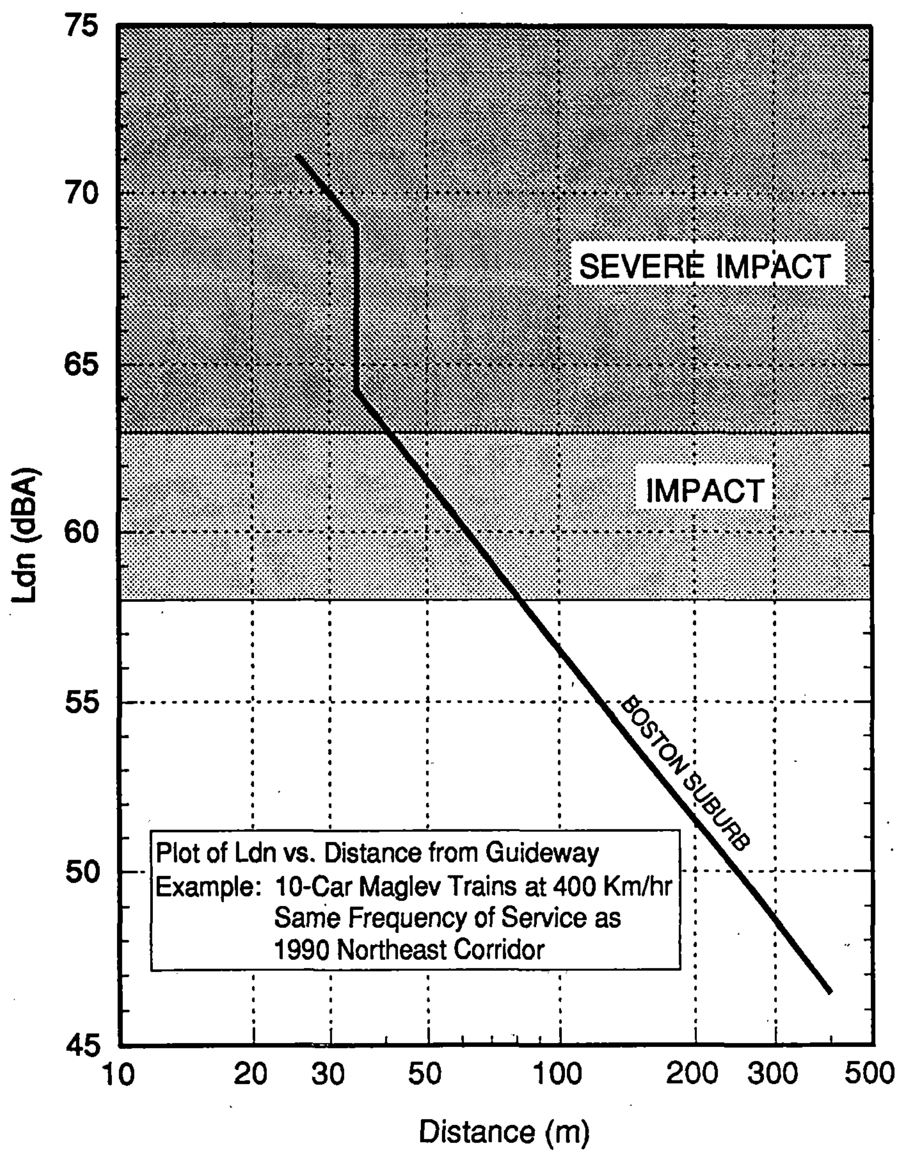


Figure 12. Ldn vs. Distance for Examples

5. REFERENCES

1. Plotkin, Kenneth J., L.C. Sutherland, J.A. Molino, "Environmental Noise Assessment for Military Aircraft Training Routes; Volume 2: Recommended Noise Metric." Wyle Laboratories Report WR 86-21 prepared for Wright-Patterson Air Force Base, AAMRL/BBE, April 1987. (NTIS No. AD-A181 278)

2. TUV Rheinland, Gerauschmessungen an der Magnetschnellbahn TR 07 und an anderen Verkehrssystemen im Vergleich (Noise Measurements of the Maglev TR 07 and Other Transportation Systems in Comparison), Institut fur Energietechnik und Umweltschutz, Bericht-Nr.: 933/329005/05-06, 4 July 1990.

3. Rosinger, G.,Nixon, D.W. and Von Gierke, H.E., "Quantification of the Noisiness of 'Approaching' and 'Receding' Sounds," J.Acoust.Soc.Am., 48, pp. 843-853, October 1970.

4. Private communication between R. Horonjeff of HMMH with Jerry Speakman, Armstrong Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio 45433.

5. Pearsons, Karl S. and Ricarda L. Bennett, "The Effects of Temporal and Spectral Combinations on the Judged Noisiness of Aircraft Sounds," Final Report FAA-NO-69-3, by Bolt, Beranek and Newman, Inc. for the Federal Aviation Administration, June 1969.

6. American Public Transit Association, "1981 Guidelines for Design of Rapid Transit Facilities," Section 2.7, Noise and Vibration, 1981.

7. U.S. Department of Transportation, Federal Transit Administration, "Guidance Manual for Transit Noise and Vibration Impact Assessment," Draft Report No. UMTA-DC-08-9091-90-1, July 1990.

8. Schultz, Theodore J., "Synthesis of Social Surveys on Noise Annoyance," Journ. Acoust. Soc. Am., Vol 63, No. 8, August 1978.

9. Fidell, S., Barber, D.S., and Schultz, T.J., "Updating a Dosage-Effect Relationship for the Prevalence of Annoyance Due to General Transportation Noise," Journ.Acoust. Soc. Am.,Vol 89, No. 1, January 1991.

10. Schultz, T.J. "Noise Rating Criteria for Elevated Rapid Transit Structures," U.S. Department of Transportation Report No. UMTA-MA-06-0099-79-3, May 1979.

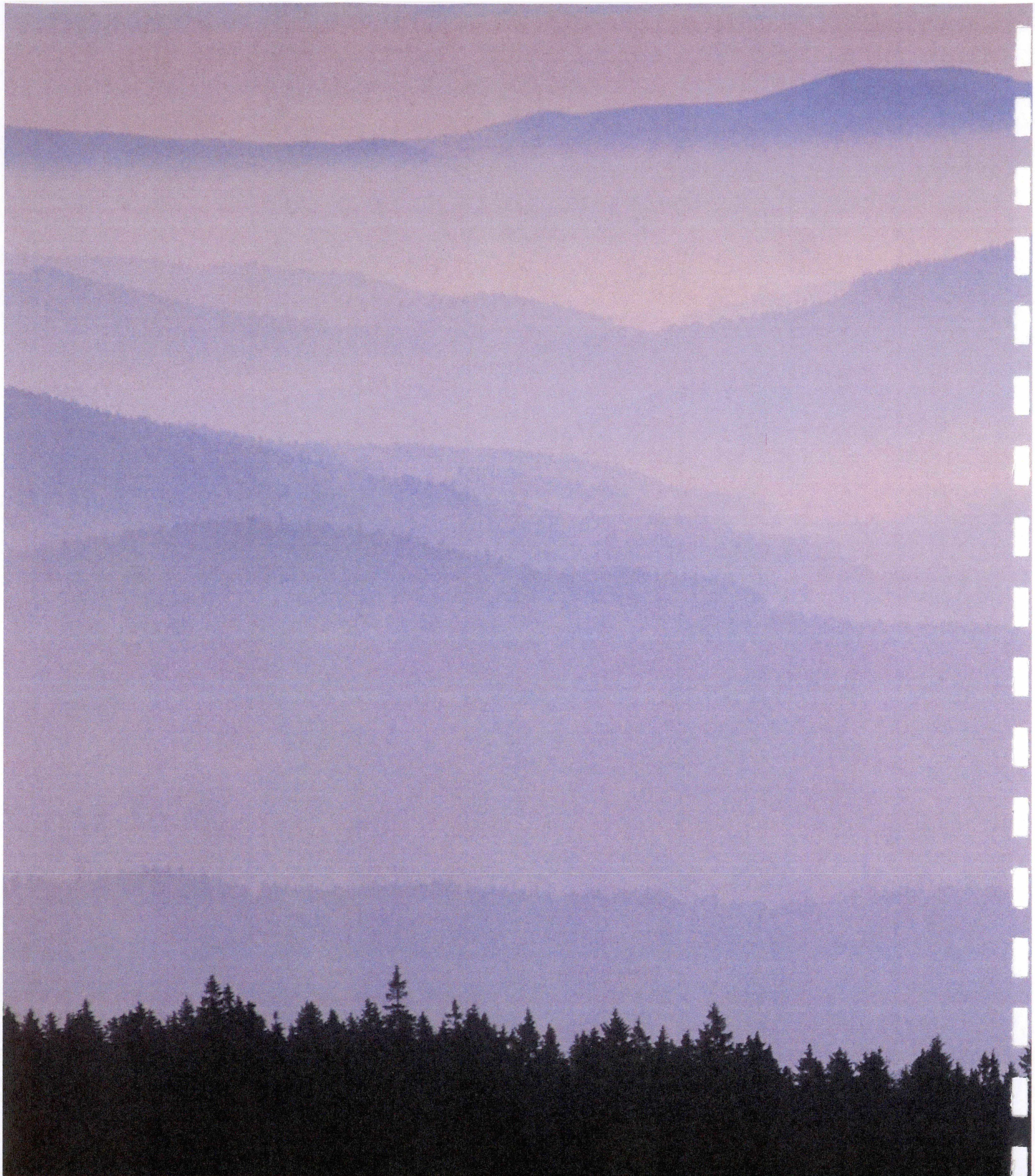
11. Anderson, G.S., "Single Vehicle Passby Program," computer program developed for the National Park Service.

12. U.S. Environmental Protection Agency, "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety," EPA report number 550/9-74-004, March 1974.

13. U.S. Department of Housing and Urban Development, "Environmental Criteria and Standards," 24 CFR Part 51, 12 July 1979; amended by 49 FR 880, 6 January 1984.

14. U.S. Department of Transportation, Federal Aviation Administration, "Federal Aviation Regulations Part 150: Airport Noise Compatibility Planning," January 1981.

Noise Criteria of High Speed MAGLEV Trains,
HMMH Report No. 291550-2 (plus 1 Draft), Carl
Hanson, 1992 -11-Advanced Systems



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