La Guardia Airport Ground-Noise Abatement Study

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An airport ground-noise abatement study was conducted for the Port Authority of New York and New Jersey along the western boundary of New York City's La Guardia Airport between 1986 and 1988. The investigation included measurements to characterize multiple noise sources, analysis of noise abatement options, and postconstruction measurements. The noise barrier design was conducted by using one-third-octave band analysis to predict expected loss of excess ground attenuation, barrier insertion loss, and net noise reduction. The study used the DIFRCT model developed by Embleton, Piercy, and Isei to calculate noise barrier insertion losses in the presence of ground effects. Although an example of one particular application and not a thorough review of the model is provided, the following conclusions were noted. The modified DIFRCT model was useful in predicting the ground effect owing to soft ground, especially at lower frequencies. In addition the study indicated that the model may be limited in its applications to hard-ground situations because of lack of coherent long-distance propagation at higher frequencies.

La Guardia Airport, located in the Borough of Queens in New York City, is operated by the Port Authority of New York and New Jersey (the Port). In response to community concerns regarding noise at La Guardia Airport during the night, the Port commissioned Harris Miller Miller & Hanson Inc. (HMMH) to conduct a noise study along the airport's western boundary. The purpose of the study was to identify major noise sources affecting residents and to assess the feasibility of using noise barriers to reduce noise levels. The residents complained of multiple night-time noise sources, but the loudest and the source of the most complaints were commercial jet aircraft departures on Runway 04.

Well-organized community members complained that noise levels and the number of sources had steadily increased for years along the western boundary of the airport. The Port's proposal to reopen the Marine Air Terminal near the airport's western boundary provoked significant community concern, and the Port agreed to undertake a noise abatement study.

The study focused on the feasibility of a noise barrier, considered to be the most comprehensive form of abatement for the numerous noise sources. In addition to appropriate locations for a barrier, the study addressed attainable insertion loss as a function of frequency, noise source, receiver location, barrier height, and barrier location. Owing to the presence of both soft and hard ground between the various source areas and the community, the analysis accounted for the effects of ground type with state-of-the-art modeling as described below.

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BARRIER EFFECTIVENESS IN THE PRESENCE OF GROUND

Noise-barrier effectiveness at airports is often limited by restrictions on barrier placement, deleterious wind conditions, and loss of soft ground attenuation. Because of the long propagation distances and the presence of soft ground, it was suspected that ground effect could play a significant role in the La Guardia study.

The upper portion of Figure 1 shows a typical noise source and receiver geometry with the direct and reflected sound paths. The difference in length between the direct and the reflected paths is commonly referred to as δ. The reflected wave must travel an additional distance δ and arrives at the receiver behind the direct wave. Assuming an infinitely rigid ground surface (hard ground), the reflected wave is not significantly affected by the ground itself and is shifted in phase by an amount corresponding to the path difference δ. The phase shift causes constructive and destructive interference (wave addition and cancellation, respectively) at the receiver that is a strong function of frequency.

The assumption of an infinitely rigid surface has been shown to be a good approximation of reflections from very hard surfaces such as old asphalt or concrete (*1*). With softer surfaces, such as grass-covered fields common at airports, phase shift occurs on reflection. In situations with such soft ground the resultant phase difference at the receiver between the direct and the reflected waves is due to the combined effects of the path length difference and the reflection phase shift. This combination causes common soft-ground attenuation when δ is small, and the reflection phase shift is nearly one-half wavelength over a wide frequency range.

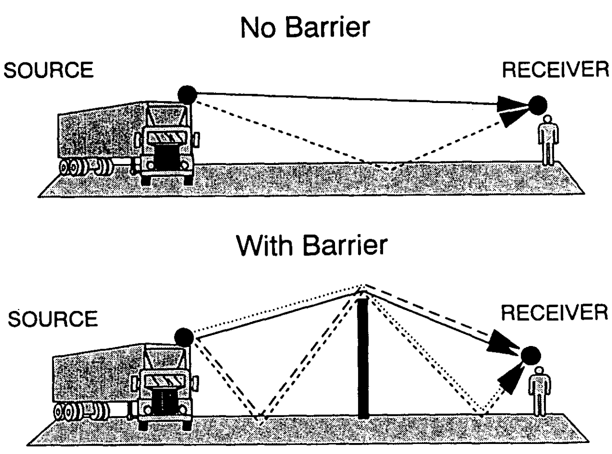

FIGURE 1 Propagation paths: (*a*) with no barrier and (*b*) with barrier.

At airports HMMH measurements have confirmed that this attenuation frequently reaches 10 to 15 dB and can span the frequency range from below 200 to above 2000 Hz.

Destructive interference, as described in a situation without a noise barrier, can also occur behind a noise barrier. Although the fundamental causes of the interference pattern are the same as in the no-barrier case, the addition of a noise barrier introduces multiple sound propagation paths. The lower portion of Figure 1 shows the most important of these paths including the direct diffracted path and three diffracted and reflected paths. Traditional barrier models do not account for these additional paths and as a result may overestimate barrier performance (*2*).

A traditional model used for barrier attenuation analysis is commonly referred to as *Maekawa Curves* (*3*). This model is based on Kirchoff-Fresnel diffraction theory and incorporates an adjustment of approximately 2 dB to account for loss of ground effect that is constant across all frequencies (i.e., the Maekawa Curves reduce the barrier attenuation predicted by free-field Kirchoff-Fresnel theory by 2 dB). This is the model used in FHWA's STAMINA 2.0 highway noise prediction computer program (*4*).

In an effort to model the attenuation of barriers in the presence of soft ground more precisely, the DIFRCT model was developed by Isei et al. (*2*). DIFRCT preserves the phase of the sound wave along each path as it propagates from source to receiver and evaluates the net wave at the receiver on the basis of multiple paths. The phase differences caused by differences in path length and the frequency-dependent phase shift on reflection are accounted for by the model.

To determine the phase shift on reflection, DIFRCT uses the specific flow resistance of the modeled ground. Delany and Bazley (*5*) had previously shown that complex ground impedance can be adequately described by flow resistance for a wide range of common materials and surfaces. Although DIFRCT was developed analytically, Piercy and Embleton (*1*) and Nicolas et al. (*3*) tested the model extensively at short distances with various ground surfaces to determine empirically values of flow resistance for modeling different types of ground.

Figure 2 shows output from DIFRCT typical of the type that was used to calibrate the model for different types of ground. The solid curve shows attenuation caused by ground effect only. The broad, deep dip is the result of destructive interference at low frequencies primarily owing to a phase shift on a reflection since the path length difference of the direct and the reflected waves is small compared with a wavelength. The dashed curve shows the ground effect with a 6-m (20-ft)-high barrier in place. This curve includes only the ground effect for the barrier and does not include barrier attenuation. The difference between the two curves is the amount of ground-effect attenuation that would be lost if a barrier were constructed. The difference is as high as about 15 dB and extends from about 400 to 2000 Hz. Because of the loss of attenuation owing to ground effect, the overall sound level (not yet accounting for barrier attenuation) increases by about 5 dB with the barrier present. In this case to depend only on the Fresnel theory without accounting for loss of ground effect could result in a 5-dB overestimation of barrier performance. Use of the Maekawa model with its assumption of an overall 2-dB loss of ground effect could result in a 3-dB overprediction.

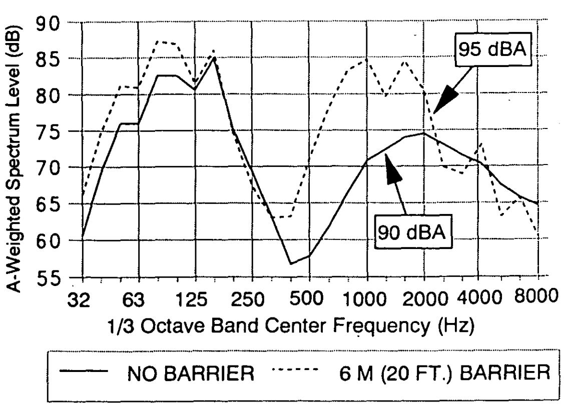

FIGURE 2 Soft-ground effect only.

Although DIFRCT correlated well with Piercy's and Embleton's test measurements for a variety of ground conditions, the model had not been used in a study with long propagation distances; therefore, the authors were concerned about the effects of atmospherics and unevenness in terrain. Some encouraging data for such a model existed, however; Parkin and Scholes (*6*) had noted evidence of coherent propagation and interference patterns at distances of up to 1000 m (3,300 ft) in a study of aircraft reverse thrust, especially at lower frequencies. HMMH modified DIFRCT to compute ground-effect interference at one-ninth-octave band center frequencies instead of one-third-octave bands. This modification made the model less sensitive to small changes in geometry and was referred to as *DIFRCT9*. DIFRCT9 combines the ninth octaves to third octaves before output. This approach was chosen instead of a numerical integration method to reduce computation time.

LA GUARDIA STUDY BARRIER ANALYSIS

Jet aircraft departures on Runway 04 were the source of the most noise complaints from the neighborhood along La Guardia's western boundary. The closest homes are approximately 425 m (1,400 ft) from Runway 04 and located relative to the runway such that they are exposed to the highest sound levels from jet engines during the start-of-takeoff roll (an angle of about 45 degrees from the rear of the engine). Maximum sound levels at one measurement site (Site 1) on the front porch of a home typically ranged from 90 to 100 dBA during jet aircraft departures.

With no noise barrier the reflection point for noise from aircraft starting takeoff roll on Runway 04 occurred on a broad area of asphalt near one of the rental car facilities approximately midway between the runway end and Site 1. The broadness of the area suggests that for slightly different geometries (e.g., as the aircraft begins to move down the runway or for a listener at one of the homes adjacent to Site 1) the reflection point would still be on asphalt. With a 6-m (20-ft) noise barrier the reflection point on the source (airport) side of the barrier is located on an area of soft ground, whereas the receiver (community) side reflection is on asphalt.

The ground-effect attenuation for the Site 1 geometry in the no-barrier case was evaluated with DIFRCT9 and revealed only a shallow and narrow dip at about 2500 Hz. This was because of the hard-ground reflection with negligible phase shift. The selected flow resistance was 20,000 cgs rayls, consistent with Embleton's measurements on asphalt. If the reflection point had occurred on soft grass (300 cgs rayls), the more significant phase shift on reflection would result in a broader and deeper ground-effect dip occurring at a lower frequency.

Figure 3 compares the DIFRCT9 calculations and the Maekawa model for a Boeing 727 departure at Site 1. The solid curve on the graph shows the recorded spectrum with no barrier present and an overall sound level of 91 dBA. The dashed curve is the computed attenuated spectrum with the Maekawa model with a 6-m (20-ft)-high barrier. The Maekawa Curve is fairly smooth, reflecting the assumptions of frequency-independent loss of ground effect and greater attenuation with increasing frequency. The dotted curve shows the prediction of the DIFRCT9 model for a 20-ft-high barrier. At the lowest frequencies (up to about 100 Hz) the output of DIFRCT9 is very close to that of the Maekawa model, but between about 100 and 1000 Hz, there is a broad, deep dip because of the effect of the airport-side reflection point on grass. Above 1000 Hz, DIFRCT9 predicts less attenuation than the Maekawa model. The peak centered at about 2500 Hz reflects the loss of the no-barrier ground-effect dip at 2500 Hz. Although the resultant spectra from the Maekawa and the DIFRCT9 analyses are very different, for this particular case the predictions of overall A-weighted insertion loss are similar: 10 dB for DIFRCT and 9 dB for Maekawa.

Although Embleton and others observed phase coherence at upper frequencies at distances of up to 15 m (50 ft), it is likely that such coherent propagation may break down over long distances because of atmospheric turbulence and small variations in ground elevation. These conclusions are supported by the observations of Parkin and Scholes (*6*), who noted phase coherence chiefly at lower frequencies at long propagation distances outdoors.

In other portions of the study area the reflection points were on hard ground in both the no-barrier and with-barrier situations. In several of these cases DIFRCT9 predicted amplification in some middle and high frequencies, and it is possible that potential insertion loss was underestimated. Because amplification in the high frequencies is not consistent with the experience of HMMH in other barrier studies over hard ground, the traditional Maekawa model was used for these situations.

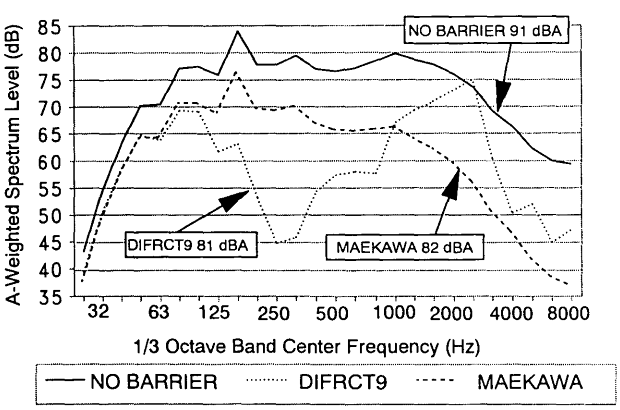

FIGURE 3 Boeing 727 departure spectrum at Site 1 with no barrier (measured) and a 6-m (20-ft) barrier.

POSTCONSTRUCTION MEASUREMENTS

In response to a request by the community, the Port and HMMH perform postconstruction measurements to determine the performance of the completed barrier. Because of dissimilar weather conditions it was not possible to perform comparison of postconstruction measurements in accordance with the standards of the American National Standards Institute (ANSI) (*7*). As a result the postconstruction measurements could not be compared directly with the preconstruction measurements. Instead the ANSI reference microphone method was used.

The data microphone was located in the same position as the microphone in the preconstruction measurements. The reference microphone was located on a post above the top of the barrier to measure the no-barrier sound level. A third microphone was located on the airport side near the base of the barrier, at a height of 1.5 m (5 ft) above the ground, to approximate the ground effect in the prebarrier situation. Adjustments were made to account for the various source-to-microphone propagation distances, for pressure doubling at the base of the barrier, and for reflections from the facade of the house at the data microphone position. Simultaneous tape recordings of approximately 30 Boeing 727 departures were made at these three locations. In addition to postconstruction measurements at Site 1, postconstruction measurements were also made at a hard-ground site on the middle block of the study area.

The postconstruction measurements gave a fair match to the predictions at Site 1, with a measured net noise reduction of 7 dB compared with a predicted reduction of 10 dB. The postconstruction measurements showed better agreement at the hard-ground site, with a measured insertion loss of 12 dB and a predicted noise reduction of 13 dB. The lack of better agreement was not unexpected because of the differences in weather conditions between the preconstruction and postconstruction measurements. Differences in wind, atmospheric turbulence, and refraction because of a temperature gradient could affect the reflection points, possibly moving a reflection point from hard to soft ground or vice versa, thus creating a different ground-effect situation than the one modeled. It is expected that the prediction at the all-hard-ground site would be more stable under various weather conditions because of the smaller role of ground effect and the lack of hard- and soft-ground boundaries.

CONCLUSIONS AND RECOMMENDATIONS

The La Guardia study demonstrated that the DIFRCT9 model is useful in predicting the ground effect due to soft ground, especially at mid and low frequencies. However the results of the study also indicate that the model may be limited in its application at higher frequencies (above 2000 Hz), particularly over hard ground, because of lack of coherence in propagation over long distances. On the basis of the results of the La Guardia and other studies, the authors continue to use the Maekawa model in the absence of soft ground. In the presence of soft ground the ground-effect portion of DIFRCT9 is used only to predict ground effect in both the no-barrier and with-barrier cases. When possible the authors also perform simultaneous measurements at multiple microphone heights to help predict the potential loss of ground effect. The authors no longer use the barrier portion of DIFRCT9 directly, but instead combine the ground-effect results of

DIFRCT9 with Fresnel theory (evaluated for the direct-diffracted path) to predict net insertion loss.

POSTSCRIPT

Since completing the La Guardia study, the authors have seen similar results in noise barrier studies at other airports, including those at Dallas Love Field, Baltimore-Washington International, and Syracuse, New York. Most recently at Syracuse HMMH made simultaneous measurements of aircraft start-of-takeoff events with microphone heights of 1.5 m (5 ft) and 7 m (23 ft) above ground level at the same location. The 1.5-m (5-ft) microphone height represented the position of a typical ground-level receiver, whereas the 7-m (23-ft) position represented the diffracting edge at the top of a potential noise barrier. Over soft ground at typical propagation distances of 450 m (1,500 ft) to 600 m (2,000 ft), the measurements indicated that the difference in ground effect between the two heights ranged between 6 and 13 dB over the broad frequency range from approximately 250 to 2500 Hz. This difference represents the loss of ground-effect attenuation that would be caused by the construction of a noise barrier and is similar to that shown in Figure 2. The ground-effect portion of DIFRCT9 agreed well with the Syracuse measurements, predicting a loss of ground effect of 8 to 15 dB over the same frequency range (*8*). This slight overprediction of loss of ground effect produces a conservative underestimation of barrier performance.

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Publication of this paper sponsored by Committee on Transportation-Related Noise and Vibration.