INTER-NOISE 2006
3-6 DECEMBER 2006
HONOLULU, HAWAII, USA

Modeling the reduced insertion loss of a sound barrier in a downward refracting atmosphere for a petrochemical plant

Frank H. Brittain[a]
Bechtel Corp.
2255 Peavine Valley Road
Reno, NV 89523
USA

David J. Parzych[b]
Power Acoustics, Inc.
12472 Lake Underhill Rd. #302
Orlando, FL 32828
USA

ABSTRACT

A noise prediction model is used in designing a petrochemical plant to meet community noise limits. Most ray-tracing software uses ISO 9613-2 to compute outdoor propagation. ISO 9613-2 uses straight sound rays in predicting the insertion loss (IL) of barriers. This tends to give unrealistically high ILs, and consequently misleadingly low sound pressure levels at receptors. A "residential" noise barrier for a petrochemical plant, located near residences, was proposed as a partial replacement for much more expensive very low-noise equipment. The alternatives to straight rays for predicting IL were curved rays or conservative guesses. If, as expected, calculations using curved rays were more accurate, and the ILs at residences were reduced by just 1 to 2 dB, millions of dollars could be saved. Commercially available community noise software was modified to include curved rays. This paper compares barrier ILs computed using both straight and curved rays. Results show that near a residential barrier ILs computed using both straight and curved rays are nearly identical. However, typically beyond about 50 to 100 m from a residential barrier, curved rays predict ILs that will often be considerably lower than predicted using straight rays.

1 INTRODUCTION

Predicting the insertion loss (IL) of barriers using methodology of ISO 9613-2 [1] is problematic in many cases [2]. The straight rays assumed by ISO 9613-2 tend to be overly optimistic when predicting barrier ILs for barriers located far from the receptors or sound sources. Predicted sound barrier ILs are often higher and sound pressure levels (SPL) lower than encountered in the field – giving predictions that tend to be unconservative. Using curved ray paths to simulate the propagation of sound in a downward refracting atmosphere (downwind) is expected to be more accurate when predicting barrier IL, particularly when the barrier in not close to either the source or receiver.

This paper address the differences between using straight and curved rays for calculating the IL of a noise control barrier, which is located near a residential area. When typical and moderate-cost noise controls are not sufficient, the incremental cost of additional controls is often extremely expensive, and often exceeds $1 million per dB of noise reduction. A "residential" barrier is sometimes used instead of far more expensive noise controls to reduce costs for controlling community noise from industrial facilities such as a petrochemical plant. A small refinery hydrotreater unit with a residential barrier was chosen to calculate the effect on barrier IL using both curved and straight ray propagation.

The model used, curved rays and their impact on barrier IL, petrochemical unit chosen, and predicted SPL predicted at various distances from a residential barrier are presented. As expected, the results show significant differences between ILs computed using straight and curved ray paths. Based on these results, conclusions are drawn and recommendations are made.

[a] E-mail Address: fhbritta@bechtel.com
[b] E-mail Address: dparzych@poweracoustics.com

2 BACKGROUND – NOISE MODELING IN PLANT DESIGN

A noise prediction model is needed to design any industrial facility, including a petrochemical plant, to meet community noise limits. The model is used to determine the noise reductions needed, choose noise limits for procuring equipment, and select add-on noise controls (controls not supplied by equipment vendors, such as thermal/acoustical insulation for pipelines, fan inlet and exhaust silencers, barriers, and enclosures). The model is also used for siting and environmental assessment. Later, the model is used to confirm that predicted levels will meet the community noise limits with an adequate margin and acceptable risks [3,4].

Until relatively recently, most noise prediction models were developed using an Excel spreadsheet. More and more models are being developed using more powerful ray-tracing software (such as, CadnaA, SoundPLAN, Mithra, and IMMI) or image-source (SPM9613) software. ISO 9613-2 is used in most ray-tracing and image-source models to compute outdoor propagation. While discussion of ray-tracing software is beyond the scope of this paper, Brittain and Hale [5] describe some of the issues in using sophisticated ray-tracing software.

For calculating barrier IL, ISO 9613-2 assumes each ray of sound is a straight line between a source and receiver. This sometimes seriously over predicts the IL, and under predicts SPL. For example, ISO 9613-2 predicts a 4.8 dB IL for grazing incidence – even when the source-barrier and barrier-receiver distances are both 1 km, in which case, the actual IL (and that calculated using curved rays) is usually zero. Barriers are much more effective when located near a source or receiver, and the IL usually decreases as distance from either the source or the receiver increases. Downwind (a downward refractive atmosphere) sound rays are curved [6], and tend to arc over the top of a barrier. As the source-barrier and barrier-receiver distances increase, the IL will decrease and sometimes be eliminated. In a downward refracting atmosphere, actual IL (and that predicted using curved rays) decreases with distance from the barrier considerably faster than predicted using straight sound rays. At any given time, the actual IL of a barrier depends heavily on atmospheric effects. Barrier IL is also frequency dependent.

As an example, Figure 1 shows a barrier with a straight (as shown in a plan view) and a curved ray. The straight ray is diffracted by the barrier and has a computed IL of 8.5 dB. The curved ray arcs over the top of the barrier without any diffraction, and has no IL.

ISO 9613-2 predicts long-term average levels under downwind atmospheric conditions favorable to propagation of sound. Actual levels will sometimes exceed the predicted average; this can cause difficulties and risks when designing a petrochemical plant to meet a not-to-exceed community noise limit [3].

3 PROBLEM DEFINITION

For a petrochemical plant with no noise controls except those normally supplied by vendors, such as combustion turbine intake and exhaust silencers, relatively inexpensive controls will normally provide significant noise reduction. (In the highly competitive bidding environment, many vendors typically bid minimal or no noise controls.) As noise controls for community noise are added, the incremental costs (in $ per dB of noise reduction) increase. After the easy and relatively inexpensive controls are included, the incremental costs increase very rapidly – not linearly, but more steeply, and possibly exponentially. Experience within the industry indicates that the rate of increase soon exceeds $1 million per dB reduction. Examples of very expensive controls can include specifying and procuring high-powered or high-speed equipment to actually meet 85 or 80 dBA at all locations 1 m from the equipment, high IL (and pressure-drop) silencers for combustion turbine exhausts, very high effectiveness pipeline lagging, enclosures for hydrocarbon compressors, and high-pressure drop control valves meeting 85 or 80 dBA at 1 m.

As would be expected, cost of noise controls is a critical competitive issue in bidding (of equipment and engineering-construction services), and in lump-sum work. Project management, and presumably the responsible noise control engineer, seek ways to reduce costs. One control that often reduces the need for very expensive controls is a long "residential" barrier, located close to a residential area that blocks the line of sight between residences and the petrochemical plant.

Residences near such a barrier will have relatively high IL, and calculations using both straight and curved rays will give nearly identical results. As the distance between the barrier and residences increases, the A-weighted IL will decrease. (The SPL also decreases with distance due to geometrical spreading, atmospheric absorption, and atmospheric effects.) Barriers close to a source will give similar results for a small source whose equipment is close to the ground. Insertion losses for large or elevated sources are more complicated, and there are no simple generalizations. Differences between computed ILs using straight and curved rays will occur primarily when the distances of the barrier from both source and receiver are large. It is here that straight rays are expected to give unrealistically high ILs, including the 4.8 dB IL. Calculations using curved rays tend to reduce this effect, and thus are expected to give more accurate predictions of IL. Brittain [3] cites 36 references related to problems with or accuracy of ISO 9613-2.

The problem investigated by this paper is how much is the predicted IL of a barrier reduced using curved rays compared to straight rays, and to assess the accuracy of using curved rays.

4 MODELING SOFTWARE

Except for software using Nord2000 [7,8,9] (exsound2000 is a very limited adaptation for point sources only and SoundPLAN has a Nord2000 module), no commercially available software for calculating barrier IL uses curved rays. (It should be noted that Nord2000 provides for calculating outdoor propagation only for a specific atmospheric condition input by the user, and not for a long-term average calculated using ISO 9613-2.) Thus, Nord2000 is difficult to use in designing petrochemical facilities to meet a not-to-exceed community noise limit. Modeling software was developed by modifying existing SPM9613 software to include curved rays for barriers without making any other changes to ISO 9613-2 calculations. Curved rays have a radius of 5000 m for barriers, which is the same radius used by ISO 9613-2 for foliage and built-up areas.

SPM9613 is image-source software that is similar to ray-tracing software for modeling industrial facilities, but is somewhat less powerful. Compared to powerful ray-tracing software SPM9613 has the following attributes:

- Calculates only the first reflection
- Uses only ISO 9613-2 to calculate outdoor propagation
- No automatic partitioning (the user selects partitions for line and area sources)
- No database features
- Far easier to reasonably master, easier to use, and far less expensive.

5 THE MODEL

A small, but typical, refinery unit – a hydrotreater – was selected to show the effect of curved rays on computed barrier IL. (Refineries are broken up into process units.) The entire Unit is about 150 x 60 m, and a symbolic layout (within the Unit) of noise sources only is shown in Figure 2. The model consists of the following noise sources with a description of how each was modeled:

- Pumps – as small squares modeled as point sources
- Air cooler with 18 cells and an elevation of 13 m – as a horizontal rectangle modeled as a horizontal area source
- Reciprocating compressor – as a rectangle modeled as a 1 m thick box.

The Unit was modeled using the modified version of SPM9613, described in Section 4, to calculate barrier octave-band and A-weighted IL and SPL with no barrier, straight rays, and curved rays with a radius of 5000 m. The sound power levels in octave bands in dB and as A-weighted level in dBA for the entire Unit are as follows:

63	125	250	500	1000	2000	4000	8000	A-Wt.
120.9	115.8	112.2	110.0	108.6	108.6	107.9	106.5	115.6

Modeling ground effects for barriers exactly follows the methodology prescribed by ISO 9613-2. Parzych [2] indicates that part of the methodology of ISO 9613-2 for ground effects on barrier IL is not always realistic. However, as hard ground (ground absorption, G = zero) was used, these effects are small. Further, the ground effects are essentially identical for both straight rays and 5000 m rays, and similar to those for no barrier.

6 CALCULATIONS AND RESULTS

Factors that affect the differences in predicted IL between straight rays and curved rays, include source-barrier and barrier-receiver distances, source height and frequency content, barrier location and height. The assumed Unit is believed to be representative. Calculations were made with no barrier and a very long residential barrier (no end diffractions) of differing heights and distances measured from the north edge of equipment in the Unit. Except as noted, hard ground (G = 0 in ISO 9613-2 notation) was used for all calculations. The model includes a receiver height of 2 m and atmospheric absorption for 15 ºC and 70 percent relative humidity. At the same distance (source-barrier and barrier-receiver), this absorption is identical. However, when comparing ILs at shorter distances with those at longer distances, atmospheric absorption increases with distance and shape of the spectra changes because higher frequencies have greater barrier IL and atmospheric attenuation than at low frequencies. Calculations were done for source-receiver distances of 100, 300, and 1000 m. These distances are measured perpendicular to the line through the northern most piece of equipment as shown in Figure 2, and through the center of the Unit.

6.1 Receiver Distance From Residential Barrier

Representative effects of curved rays on SPL as a function of barrier-receiver distance are shown in Figure 3a,b,c. The annotation of “with /std barrier” means IL calculations in full compliance with ISO 9613-2 barrier calculations, and “barrier w/5000m” means IL calculations using curved rays with a radius of 5000 m (otherwise according to ISO 9613-2). These are for a barrier height of 6 m. The levels for no barrier and a barrier using ISO 9613-2 straight ray calculation methodology are much as expected. The levels computed using a curved ray with a 5000 m radius, show reductions in IL relative to the straight-line ray paths. The IL is the difference between the level for no barrier and level for one of the barrier curves – at the same distance from the barrier. The approximate IL can be estimated from the curves. For Figure 3 only, a Unit-barrier distance of 100 m and barrier-receiver distances less than roughly 40 m, both barrier calculations are nearly identical. Starting at 300m from the Unit, the SPL approaches the no barrier case (the IL approaches zero) for larger barrier-receiver distances.

6.2 Barrier Height

Figures 4 and 5 are identical, except that the barrier heights are 4 and 9 m, respectively. Comparing Figures 3, 4, and 5 the effect of barrier height can be seen – the higher the barrier the greater the IL, but this effect decreases with distance from the barrier. At larger distances from the barrier, the 4.8 dB IL for grazing incidence tends to disappear in the field and in curved ray IL calculations.

6.3 Ground Absorption

All previous calculations are for hard ground (G = 0). Similar, but "muted" results (SPL and ILs) can be obtained for soft ground (G = 1). These are more difficult to interpret, because the ISO 9613-2 essentially sets the barrier IL to the greater of either the barrier attenuation or the ground attenuation. If the ground attenuation becomes large relative to the barrier attenuation, only the effects of the ground attenuation will be present.

7 CONCLUSIONS

Because only residential barriers were evaluated, it is difficult to draw definitive conclusions that apply to all cases. However, the following conclusions can be drawn:

1. Insertion losses predicted using curved rays tend to eliminate most or all of the problems identified for larger source-barrier and barrier-receiver distances.
2. Results confirm the expectation both that IL from straight and curved rays tend to deviate as distance from a barrier increases, and that calculations using curved rays are significantly more accurate when the source-barrier and barrier-receiver distances are relatively large.
3. Results tend to confirm the expectation that curved and straight rays give nearly identical results when the receiver is located near the residential barrier.
4. As the barrier height increase, the IL also increases.
5. Using straight rays to predict the IL for a residential barrier can induce serious errors in A-weighted IL beyond about 60 m.
6. It strongly appears that straight rays will more closely approximate the best possible ILs achievable, and curved rays will better approximate long-term downwind average ILs.
7. It appears that ILs computed using curved rays would be higher than that for no barrier, and lower than computed using straight rays. The SPL plotted in Figures 3 to 5 for curved rays will lie between the curves for no barrier and a barrier with straight rays.
8. The IL for curved rays appear to be more conservative than those for straight rays.
9. For large petrochemical, process, or industrial facilities, source-barrier distances will vary considerably, and the results presented here should only be used as a general guideline.
10. Using straight ray calculations based on ISO 9613-2 can be seriously unconservative when designing a sound barrier for a petrochemical plant or other industrial facility to meet a not-to-exceed community noise limit.

8 RECOMMENDATIONS

The following recommendations are made:

1. Curved rays should be using in modeling when source-barrier or barrier-receiver distances are relatively large – when the requisite software is available.
2. Provisions for curved rays for barrier IL calculations should be added to ray-tracing and image-source software.
3. New standards for outdoor propagation should include curved-rays for calculating IL of barriers. (This includes the current US revision of ISO 9613-2 as ANSI S12.62.)

9 REFERENCES

[1] ISO 9613-2, “Acoustics — Attenuation of sound during propagation outdoors — Part 2: General methods of calculation, International Standards Organization, Genève, Switzerland, 1996.

[2] Dave Paryzch, “Handling of barriers in ISO 9613-2,” Special Session on ISO 9613-2, *Proc. NOISE-CON 2004*, Baltimore, (Noise Control Foundation, Poughkeepsie, New York, 2004).

[3] Frank Brittain, “Using ISO 9613-2 for designing facilities to meet a not-to-exceed community noise limit,” Proceedings of Noise-Con 2004, Baltimore, MD, 12-14 July 2004.

[4] Frank Brittain, “Risks in designing power plants to meet noise limits and how to manage them,” Proceedings Noise-Con 2000, Newport Beach, California, 3-6 December 2000. (Invited paper)

[5] Frank Brittain and Marlund Hale, “Issues in using ray-tracing software for predicting community noise from power plants,” Proceedings of Noise-Con 2003, Cleveland, OH, 23-25 June 2003. (Invited paper)

[6] T.F.W. Embleton, “Tutorial on sound propagation outdoors,” J. Acoust. Soc. Am., **100**, pp. 31–48, (1996).

[7] Jørgen Kraugh, Svein Storeheier and Hans Jonasson, *Nordic Noise Prediction Method, Nord2000, Summary Report: General Nordic Sound Propagation Model and Applications in Source-Related Prediction Methods*, Delta Acoustics for Nordic Noise Group, Report AV 1717/01 (Lyngby, Denmark, revised June 2002).

[8] Jørgen Kraugh, Svein Storeheier and Hans Jonasson, *Nord2000, Comprehensive Outdoor Sound Propagation Model — Part 1: Propagation in an Atmosphere without Significant Refraction*, Delta Acoustics for Nordic Noise Group, Report AV 1849/00 (Lyngby, Denmark, December 2000, revised December 2001).

[9] Jørgen Kraugh, Svein Storeheier and Hans Jonasson, *Nord2000, Comprehensive Outdoor Sound Propagation Model — Part 2: Propagation in an Atmosphere with Refraction*, Delta Acoustics for Nordic Noise Group, Report AV 1851/00 (Lyngby, Denmark, December 2000, revised December 2001),

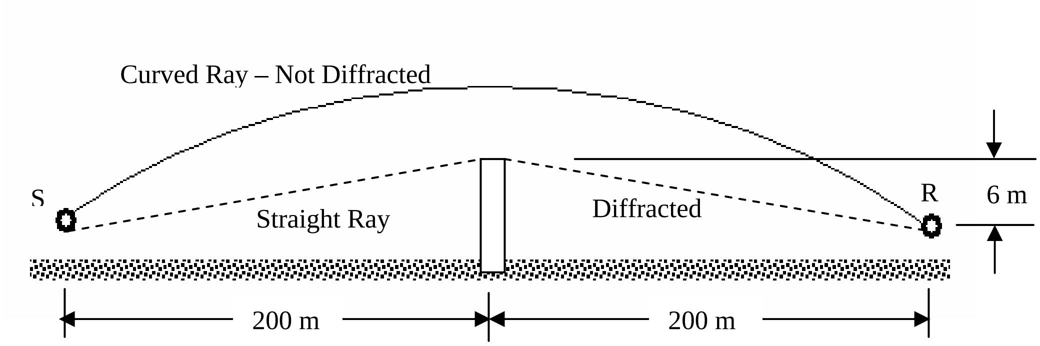

Figure 1: A barrier showing both straight and curved rays. The straight ray (when shown in a plan view) is diffracted, and has a computed IL of 8.5 dB, while the curved ray arcs over the top of the barrier with no IL.

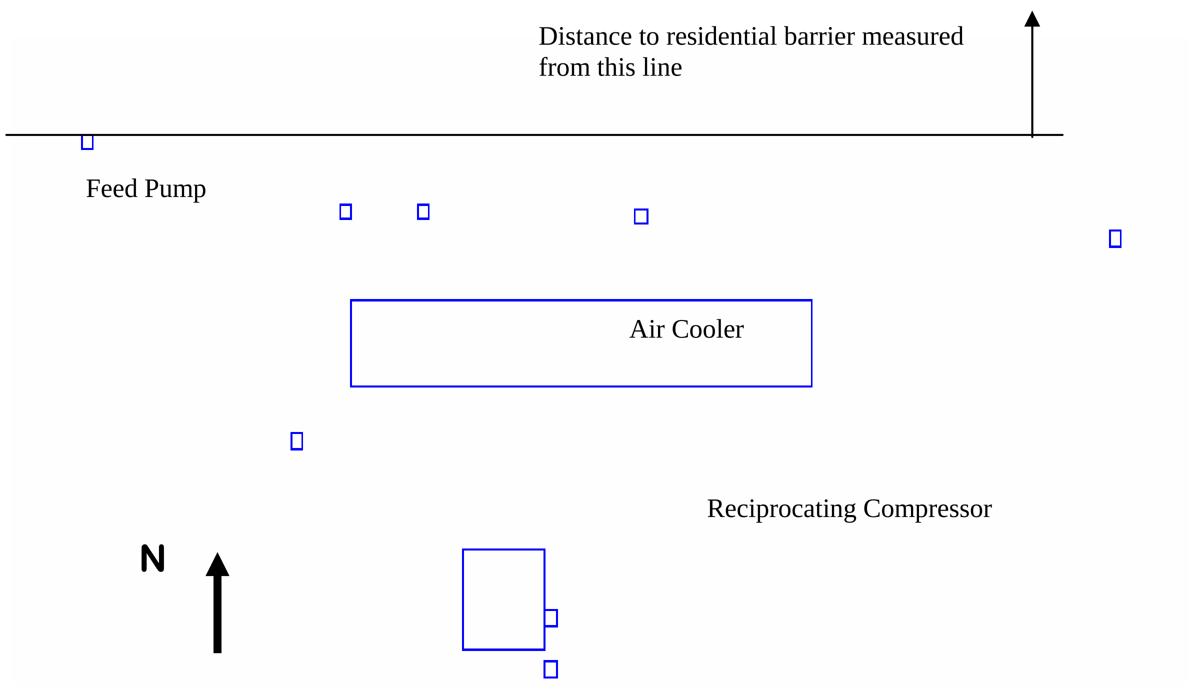

Figure 2: Sketch showing the location of noise sources modeled, and how the distance between the Unit and the residential barrier was measured.

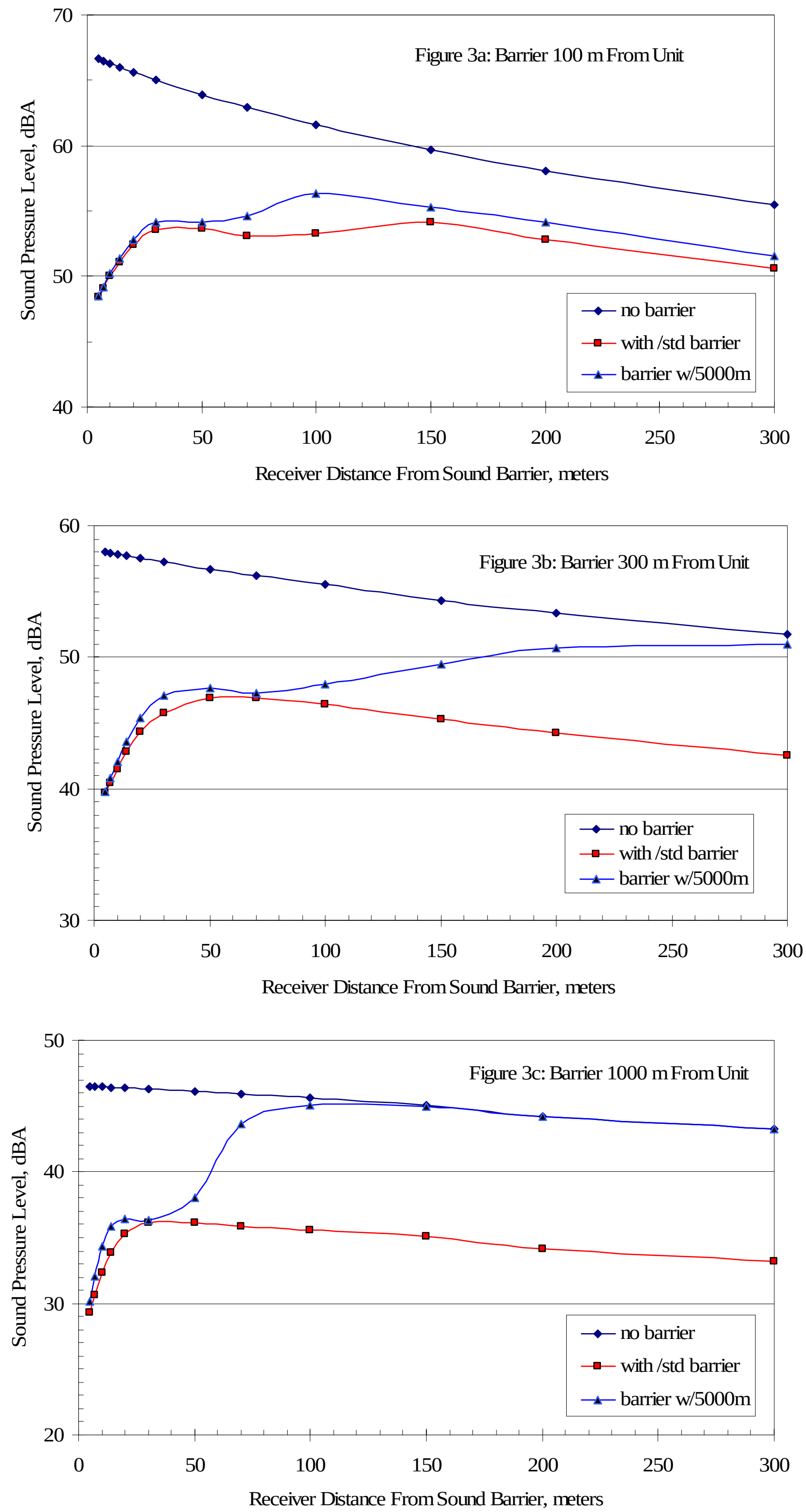

Figure 3: Sound pressure level as a function of distance from a residential barrier with a barrier height of 6 m for three different distances between the Unit and the barrier.

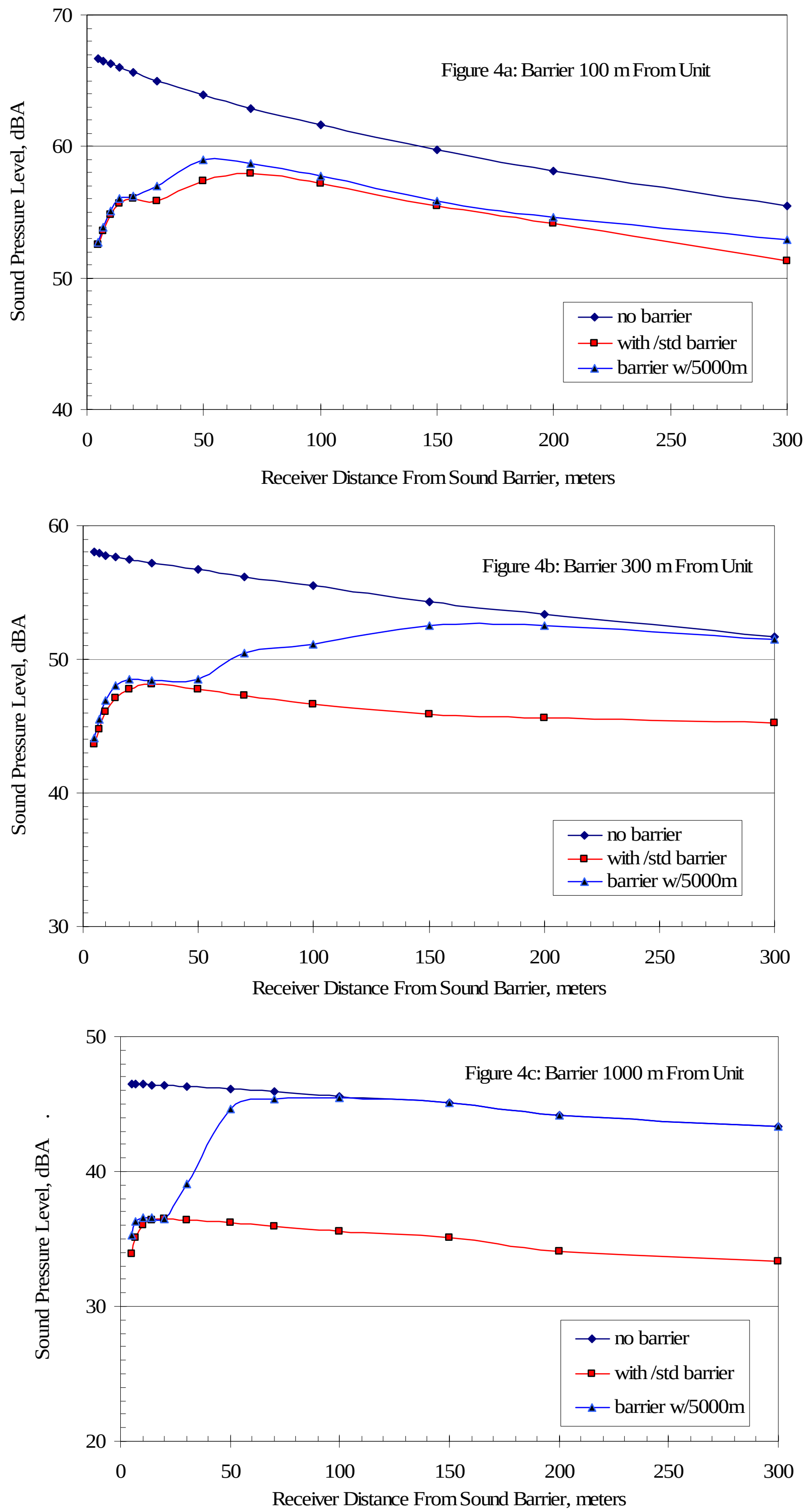

Figure 4: Sound pressure level as a function of distance from a residential barrier with a barrier height of 4 m for three different distances between the Unit and the barrier.

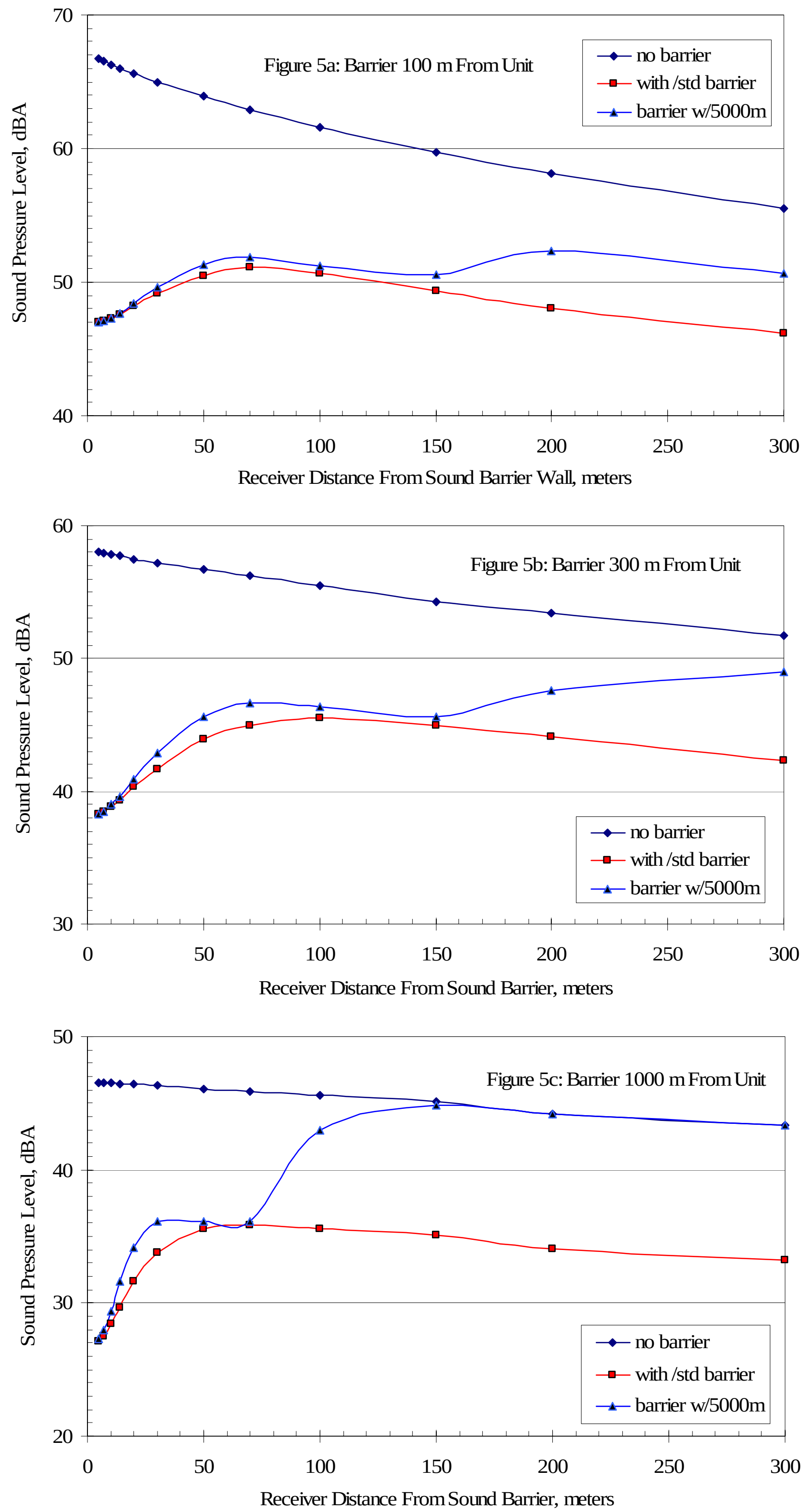

Figure 5: Sound pressure level as a function of distance from a residential barrier with a barrier height of 9 m for three different distances between the Unit and the barrier.

The proceeding paper was authored by **Dave Parzych, Principal Acoustical Consultant and Noise Control Consultant of Power Acoustics, Inc.**

For more information on how Power Acoustics, Inc. can help you, contact us at:

12472 Lake Underhill Rd, #302 • Orlando, Florida • 32828
Phone: (407) 381-1439 • Fax: (407) 381-6080
Email: info@poweracoustics.com

To see more about Power Acoustics, Inc. visit our website http://poweracoustics.com or view more technical papers at: http://poweracoustics.com/publications.html