Model for the Prediction of Noise Generated by Fixed Sources*

Modelo para la predicción del ruido proveniente de fuentes fijas

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Abstract

Objective: This article proposes a prediction model applicable to the propagation of noise generated by fixed sources as the result of the analysis of the phenomena related to the generation and propagation of sound levels and the subsequent correlation between the estimated levels and the data recorded in the field. *Materials and methods:* An experimental program was designed that included the measurement of sound pressure levels with a sound level meter in free field conditions for different weather conditions and distances from the noise emission source for comparison with the levels estimated by ISO 9613 Part 2. A statistical analysis of the data recorded in the field was performed to observe their dependence on the meteorological variables recorded during the measurements. *Results and discussion:* The standard error for the proposed prediction method is 11.4 dB(A), and the absolute average error is 9.1 dB(A). The correlation coefficient of the proposed model is 0.87. A statistically significant relationship exists between the variables at the 95 % confidence level. *Conclusion:* A propagation model that presented a better fit than the method of ISO 9613 Part 2 and a higher correlation coefficient was obtained.

Keywords: ISO 9613 Part 2, noise, noise propagation

Resumen

Objetivo: Este artículo propone un modelo de predicción aplicable a la propagación del ruido proveniente de una fuente fija de emisión de ruido como fruto de un análisis de los principales fenómenos relacionados con la generación y propagación de los niveles sonoros y la posterior correlación entre los niveles estimados con los datos registrados en campo. *Materiales and métodos:* Se diseñó un programa experimental que comprendió la medición de los niveles de presión sonora con un sonómetro en condiciones de campo libre para diferentes condiciones meteorológicas y distancias de la fuente de emisión de ruido para compararlos con los niveles estimados por la norma ISO 9613 Parte 2. Se realizó un análisis estadístico de los datos registrados en campo para observar la dependencia con las variables meteorológicas registradas durante las mediciones. *Resultados y discusión:* El error estándar del método de predicción propuesto es de 11.4 dB(A) y el error absoluto medio de 9.1 dB(A). El coeficiente de correlación del método propuesto es 0.87. Hay una relación estadísticamente significativa entre las variables en un nivel de confianza del 95 %. *Conclusión:* Se obtuvo a un modelo de propagación que presenta un mejor ajuste que el método de la norma ISO 9613 Parte 2 y un coeficiente de correlación mayor.

Palabras clave: norma ISO 9613 Parte 2, ruido, propagación del ruido

Introduction

According to a poll conducted by P. E. Mediterranean Acoustics Research & Development (PEMARD) at the end of 2011, members of the Acoustics Institute (IOA) and the Acoustical Society of America (ASA) were asked about which outdoor sound propagation method or model they use more often. Of the thirty-eight responses, 71 % still prefer the ISO 9613 method. This standard is an empirical method that has many limitations and yields results that are inaccurate and imprecise [1].

According to P. Economou and P. Charalampous, the weakest parts of the implementation of this method are the flexibility of the method and that uneven ground cannot be properly modeled. Calculations are carried out in octave bands, and sound energy calculations remove interference effects, just to mention a few. Bearing in mind its lack of accuracy and its crude model representation, one wonders why it is still the preferred method [1].

As stated by Wondollek, according to the ground attenuation equations of the model from standard ISO 9613 Part 2, soil attenuation should be approximately 0 dB for porous soil above 125 Hz. Accordingly, porous soil would produce a ground attenuation equal to zero, whereas hard soil would result in reinforcement. Another fact that must be taken into account is that the source height has no influence on the ground effect when it is greater than 10 m, and the ground effect is independent of the average size of the area [2].

International standard ISO 9613 Part 2 specifies an engineering method for calculating sound attenuation during outdoor propagation to predict sound pressure levels at certain distances from various sources [3]. In this method the source of noise emission is considered a point source, and sound emission at any receiver is predicted with reasonable accuracy under conditions that are favorable for the propagation of sound [4].

The model can be used for estimating noise levels using a specific receptor for common sources of noise emission in relatively simple environments, such as when the distances separating the source from the receptor are relatively small and when there are no intervening structures that impede the noise propagation. That is, when there is direct propagation. However, the level of uncertainty that still exists in the prediction of noise levels using current analytical and empirical models can be significant. Therefore, a good model for noise propagation that considers the effects of weather conditions is necessary to accurately predict noise levels generated by fixed sources.

The method of ISO 9613 Part 2 predicts sound pressure level during outdoor propagation under weather conditions that are favorable for the propagation of emitted noise [5]. These conditions are summarized as follows:

- The wind blows from the source to the receptor within an angle of ±45º in a direction that connects the center of the dominant sound source with the center of the reception area being considered.
- The speed of the wind is 1-5 m/s (measured from an altitude of between 3 and 11 m from the ground surface).
- Well-developed, moderate thermal inversion conditions that as commonly occur on calm, cloudless nights.
-

The downwind equivalent continuous sound pressure levels in octave bands at a specific receptor a certain distance from a source may be calculated using the equation 1 [5]:

$$L_P = L_W + D - A_{div} - A_{atm} - A_{gr} - A_{bar} - A_{misc} \tag{1}$$

where
L_P = Sound pressure level in octave bands at a specific receptor, dB(A)
L_W = Level of sound power in octave bands produced by a sound point source, dB(A)
D = Directionality factor, dB(A)
A_{div} = Attenuation due to geometrical divergence, dB(A)
A_{atm} = Attenuation due to atmospheric absorption, dB(A)
A_{gr} = Attenuation due to the ground effect, dB(A)
A_{bar}= Attenuation due to a barrier, dB(A)
A_{misc} = Attenuation due to miscellaneous other effects, dB(A)

General methods for calculating A_{div}, A_{atm}, A_{gr} and A_{bar} are specified in ISO 9613 Part 2. Information on three contributions to the last term A_{misc} (the attenuation due to propagation through foliage, industrial sites and housing areas) is given in annex A of ISO 9613 Part 2. The continuous downwind sound pressure levels obtained with equation 1 are for each octave band.

Due to the wide range of uses of the noise prediction model and the numerous factors that influence sound pressure levels in open field, no procedure exists for defining a detailed model that would be adequate for each specific application [6].

Atmospheric stability strongly affects the vertical profile of wind and the force of turbulence in the atmosphere [7]. Variations in temperature influence air density and, consequently, in the velocity of sound wave propagation.

Recently, some studies that have begun to consider the influence of atmospheric stability on sound propagation have been reported [7] and [8]. Atmospheric conditions play a dominant role in the sound pressure level caused by a given noise emission source at a particular location and time. Different prediction models have different ways of considering atmospheric conditions. Standard ISO 9613 Part 2 considers propagation conditions to be simultaneously downwind in all directions (*i.e*., the model favors sound propagation from a source to any receptor to a certain degree) during a moderate thermal inversion. However, it does not consider the absolute worst-case scenarios in the environment, so it is possible that the actual impact exceeds the predicted impact [8].

The effects of weather conditions on the propagation of the sound are not significant over short distances, but for larger distances, weather conditions become more relevant as the respective heights of the source and the receptor increase [5].

Materials and Methods

In this study, an experimental program was designed to test the accuracy of the predictive method proposed by standard ISO 9613. This included measuring sound pressure levels in free field conditions under given weather conditions at various distances from a noise emission source and comparing them against the estimated sound pressure levels by standard ISO 9613 Part 2. The residual values serve as an input to develop and propose an improved model. There were no acoustic barriers.

The readings were performed on the Medellin University grounds, in the sports arena, alternating between the synthetic soccer field and the adjacent parking lot. The readings were obtained when classes were not being conducted to avoid movement throughout the entire sports area and additional noise sources. Different sites were selected for taking the readings, all of which were downwind from the noise emission source.

To simulate noise from various types of industrial activities or from emission sources that are typical of a city with characteristics like those of Medellin, previously recorded tracks on an iPod were played on a Bose speaker placed at a height of 30 cm above the ground.

An experimental design was made to select the sample size. Sixty- three (63) measurements were made at different distances from the speaker to appreciate the gradual decrease in sound pressure levels. The sound pressure levels in the octave bands at each of the measurement points were measured simultaneously with weather variables that allowed the authors to determine the class of the atmospheric stability, including the wind speed, cloud cover, solar incidence angle, ambient temperature and relative humidity. Both values were averaged over a period of 10 min. The sound pressure levels were registered and measured with a Casella CEL 633C class 1 sound level meter with the microphone placed at an altitude of 1.2 m above ground level; this was repeated at various distances (ranging from 2 m to 64 m) downwind from the speaker, as prescribed in standard ISO 1996 [9].

The procedure that was employed to measure the power levels of the sound in an open field from the values of the sound pressure level measured in the near vicinity was stipulated by standard ISO 3744 [10].

The final step consisted of analyzing the effects of the atmospheric stability on the noise propagation originating from a fixed noise source. Adjusting the prediction model to the experimental data led to improvements of the model. This model was then used to predict sound pressure levels at a specific receiver at some distance from the noise source for a wide range of weather conditions. The prediction model chosen for this study was based on the one proposed in standard ISO 9613 because it covers the principal sound pressure attenuation mechanisms, although these may be improved.

A detailed statistical analysis was performed using the data obtained in the field to study the dependence of the residual sound pressure level with the remaining parameters that were observed (the independent variables) during the measurements.

The statistics software Statgraphics Centurion XVI version 16.1.11 (Statpoint Technologies, Inc) was used to analyze the data and obtain the mathematical model. The variables that were inserted into the mathematical model were selected through the statistical software XLSTAT 2009.1.02 (Addinsoft) using principal component analysis. The variables that exhibited a correlation with the residual sound pressure level (either positive or negative and from highest to lowest) were introduced one by one into the mathematical model until an equation was obtained which explained the differences between the measured sound pressure levels and their estimated values.

Using the data obtained from the measurements and comparing them with the estimated levels, a calculation procedure was developed to predict the noise emanating from a noise source. The calculation method includes the parameters that generally affect sound pressure levels. The adjusted model shows the dependence that exists between the attenuation due to the atmospheric stability and the remaining independent variables.

To determine how to simplify the model, the highest *p-value* was considered for the independent variables. If the *p-value* was lower than 0.05, it can be noted that a statistically significant relationship exists between the variables in a 95 % confidence level. Therefore, no variable should be removed from the model. The R^2 statistic indicates the percentage to which the model explains the variability of the dependent variable. The standard error of the estimation may be used to construct prediction limits for new observations.

This analysis presents an equation for the adjusted model for attenuation due to atmospheric stability. The data were processed to determine the correlations between the residual sound pressure level, wind speed, atmospheric stability, distance, and incidence angle.

For this purpose, a multiple regression was conducted to analyze the correlations between the measured data in which the dependent variable is the residual sound pressure level given by the method established by standard ISO 9613 Part 2, with the following adjustments:

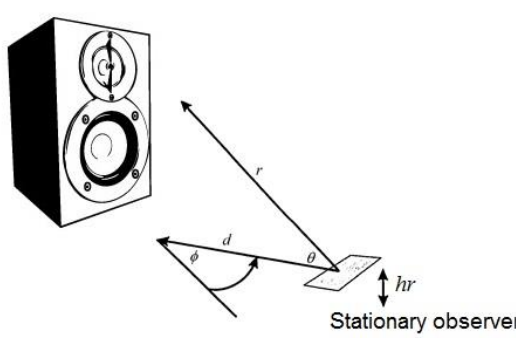
Directionality Factor

The equations for sound directionality proposed by Brooks, Pope, and Marcolini [11], [12] and [13] are used in this study. These equations are the same as those expressed by Hoogzaad [14], wherein the sound directionality depends on not only the position of the receptor with respect to the noise emission source but also the wind speed.
For high frequencies (≥ 1000 Hz), the sound directionality factor is expressed by the equation 2 [11], [12] and [13]:

$$\overline{D_h}(\theta,\phi)=\frac{2\,sin^2\left(\theta/_2\right)sin^2(\phi)}{(1+M\,cos\,\theta)[1+(M-M_c)\,cos\,\theta]^2} \tag{2}$$

where M is the Mach number from the supporting surface in motion, M_c ($M_c=0.8\,M$) is the number of convective Mach based on the flow at the trailing edge, and θ and ϕ are the angles of directionality, as shown in figure 1.

Figure 1. Angles used in the directionality factors



Source: own elaboration

The sound directionality factor for low frequencies (< 1000 Hz) is expressed by the equation 3 [11] and [15]:

$$\overline{D_l}(\theta,\phi) = \frac{sin^2\left(\theta/2\right) sin^2\,\phi}{(1 + M\,cos\,\theta)^4} \tag{3}$$

Attenuation due to Ground Effects

The propagation of sound near the ground depends on the impedance level of the surface [16]. Porous surfaces allow sound to penetrate and therefore to be absorbed, submitting it to a phase change through friction and thermal exchanges [4].

Ground attenuation is calculated using the spherical reflection coefficient of the sound wave, as shown in the equation 4 [17]:

$$A_{gr} = 20\,log\frac{1}{|Q|} \tag{4}$$

The spherical reflection coefficient is related to the reflection coefficient of the plane wave R_p by means of the equation 5 [17]:

$$Q = R_p + \left(1 - R_p\right)F \tag{5}$$

where F is the coefficient of loss at the interaction boundary between the front of the wave and the finite impedance surface, which is a function of the distance, the ground impedance, and the angle of incidence.

When the angle of incidence is greater than 5º, $F \rightarrow 0$, which indicates that the orb shape of the front of the wave need not be considered [18]. The plane wave reflection coefficient is determined from the equation 6 [17]:

$$R_p = \frac{sin\,\theta\, - {Z_{air}}/{Z_{ground}}}{sin\,\theta\, + {Z_{air}}/{Z_{ground}}} \tag{6}$$

where

θ = Angle of incidence of the sound wave, °

Z_{air} = Characteristic impedance of air at 20 °C (415 Ns/m^3)

Z_{ground} = Complex impedance of the ground, Ns/m^3

Various approximations have been formulated to determine ground impedance [17]. The Delany-Bazley model is characterized by its simplicity since it requires only one parameter, *i.e.*, the flow resistivity. It is an empirical model based on a regression analysis of acoustic properties and the resistivity of air flows at the ground surface [19] (equation 7):

$$Z_{ground}/Z_{air} = 1 + 9.08\left(\frac{f}{\sigma}\right)^{-0.75} + i11.9\left(\frac{f}{\sigma}\right)^{-0.73} \tag{7}$$

where
f = Frequency, Hz
σ = Resistivity of air flows at the ground surface, g/(s·cm^2)

Typical values for air flow resistivity at the ground surface for different types of surfaces are shown in table 1.

Table 1. Resistivity of airflow at the ground surface for different types of ground surfaces

Description of the surface	Resistivity of airflow at ground level g/(s·cm^2)
Plowed soil with no vegetation	10-20
Freshly fallen dry snow	15-30
White snow	25-50
Sowed field	50-70
In a pine or fir forest	20-80
Soil with weeds and vegetation having a height of approximately 30 cm and a diameter of 1 mm to 2 mm	90-95
Sand	100-140
Grass, rough grass	150-300
Compact and hard soil	400-500
Wet grass	700-850
Compacted sand sediment	800-2500
A thick layer of clean limestone fragments (mesh, 12 mm-25 mm)	1500-4000
Exposed soil soaked with rainwater	4000-8000
Fine dust from a road, very hard and compacted by vehicles	5000-20,000
Asphalt currently in use and sealed with dust	> 20,000
Concrete	10,000-100,000

Source: Lamancusa [20]

Attenuation due to Effects of Atmospheric Stability

The atmospheric stability significantly affects the vertical wind profile and the atmospheric turbulence [7]. Variations in temperature influence the density of air and, consequently, the velocity of propagating sound waves.

The model proposed for attenuation due to effects of atmospheric stability is given by the equation 8:

$$A_{st} = 25.4039 - 12.306\, C_{st} + 0.0716155\, C_{st}\theta + 0.177727\, C_{st}\, r - 1.90774\, \sigma_y + 2.24058\, U - 25.1352\, e^{-\left(\frac{h_r}{\sigma_z}\right)^2} \quad (8)$$

where
C_{st} = Class of atmospheric stability
σ_z = Vertical propagation coefficient, m
σ_y = Horizontal propagation coefficient, m
θ = Angle of incidence of the sound wave, °
h_r = Height of the receptor, m

Table 2 presents the classes of atmospheric stability and their relationship to the categories established by Pasquill [21].

Table 2. Atmospheric stability classes

Stability	Description	c_{st}
A	Very unstable	1
B	Moderately unstable	2
C	Slightly unstable	3
D	Neutral	4
E	Slightly stable	5
F	Stable	6

Source: own elaboration

To calculate the horizontal σ_y and vertical σ_z propagation coefficients using a mathematical model, the model proposed by McMullen through the equation 9 [21]:

$$\sigma = e^{\left[I + J\, ln\left(\frac{r}{1000}\right) + K\left(ln\left(\frac{r}{1000}\right)\right)^2\right]} \quad (9)$$

where
σ = Propagation coefficient, m
r = Distance between the source and the receptor, m
I, J, K = Empirical constants for each stability class

By comparing the dispersion of atmospheric contaminants and their relation to atmospheric stability, the horizontal and vertical dispersion coefficients from the Gaussian dispersion model were introduced into the multiple regression, which resulted in a positive correlation between the coefficients and the residual sound pressure level established in ISO 9613 Part 2. From this point forward this article will refer to the dispersion coefficients as propagation coefficients.

The propagation coefficients represent the degree of vertical and horizontal dispersion of the sound pressure levels. High standard deviation values are obtained from an atmosphere that is unstable and turbulent, whereas low values are produced by less turbulent atmospheric conditions. Table 3 shows the value of the constants for McMullen's equation.

Table 3. Constants for the propagation coefficients according to the atmospheric stability class

Stability	σ_y (m)			σ_z (m)		
	I	*J*	*K*	*I*	*J*	*K*
A	5.357	0.8828	-0.0076	6.035	2.1097	0.2770
B	5.058	0.9024	-0.0096	4.694	1.0629	0.0136
C	4.651	0.9181	-0.0076	4.110	0.9201	-0.0020
D	4.230	0.9222	-0.0087	3.414	0.7371	-0.0316
E	3.922	0.9222	-0.0064	3.057	0.6794	-0.0450
F	3.533	0.9181	-0.0070	2.621	0.6564	-0.0540

Source: Molina [21]

Results

Table 4 presents the results obtained by the noise propagation models according to the measured data. Tables 5 and 6 present differences between the measured sound pressure levels with A-weighting filters and those estimated by both the proposed propagation model and the model from ISO 9613 both in its original form and with some variations.

Table 4. Comparison of statistics between the propagation model from ISO 9613 and the proposed model

Statistic	ISO 9613	Proposed model
R^2	65.6	74.9
Standard error	13.3	11.4
Average absolute error	10.7	9.1
Correlation coefficient	0.81	0.87

Source: own elaboration

In tables 5 and 6, it can be observed that the proposed propagation model is more accurate than the method from ISO 9613 Part 2 because it exhibits values for both the standard deviation and maximum and minimum residual sound pressure levels which are lower than those obtained using the method from ISO 9613 Part 2. Using the proposed propagation model, the residual sound pressure varies between -40.3 and 33.9 dB(A), with an average of -1.9 dB(A). The residual for the wide band (20 to 20,000 Hz) equivalent continuous sound pressure level varies between -32.5 and 31.4 dB(A), with an average of -6.7 dB(A).

After eliminating the 5 % of data that were considered atypical due to studentized residuals greater than 2, the proposed model exhibits much better fit and a lower absolute average error. The studentized residuals measure the divergence of the observed residual sound pressure levels from the adjusted model using all the data and the standard deviation as a criterion.

Table 5. Differences between the estimated sound pressure levels and those measured for all stabilities, frequencies, and measurement points

Equivalent continuous sound pressure level	Residual sound pressure level (dBA)			
	Median	Maximum	Minimum	Standard Deviation
L_{Aeq} ISO 9613 method	0.0	44.5	-48.9	16.2
L_{Aeq} proposed method	-1.9	33.9	-40.3	13.4
L_{Aeq} proposed method (atypical data excluded)	-1.4	32.7	-32.4	10.9

Source: own elaboration

Table 6. Differences between the estimated sound pressure levels and those measured in a wide band (20 to 20,000 Hz) for all types of stability and measurement points

Equivalent continuous sound pressure level	Residual sound pressure level (dBA)			
	Median	Maximum	Minimum	Standard Deviation
L_{Aeq} ISO 9613 method	-2.5	40.5	-37.3	16.5
L_{Aeq} proposed method	-6.7	31.4	-32.5	12.6
L_{Aeq} proposed method (atypical data excluded)	-5.7	12.9	-19.7	8.5

Source: own elaboration

Furthermore, the residual sound pressure level varies between -32.4 and 32.7 dB(A), with an average of -1.4 dB(A). The residual for the wide band (20 to 20,000 Hz) equivalent continuous sound pressure level varies between -19.7 and 12.9 dB(A), with an average of -5.7 dB(A).

Tables 7 and 8 show statistics for the differences between the measured and estimated sound pressure levels for both the proposed propagation model and for ISO 9613 in its original form and with several variations.

Table 7. Statistics for the residual equivalent continuous sound pressure level for all types of stability, frequencies, and measurement points

Equivalent continuous sound pressure level	Data percentage (%)			
	≤ 3 dB(A)	3-6 dB(A)	6-9 dB(A)	> 9 dB(A)
L_{Aeq} ISO 9613 method	23.2	11.4	13.4	51.9
L_{Aeq} proposed method	21.2	15.0	15.6	48.2
L_{Aeq} proposed method (atypical data excluded)	23.4	17.3	17.8	41.4

Source: own elaboration

It may be observed in tables 7 and 8 that the proposed propagation model is more accurate than the method from standard ISO 9613 Part 2 because it exhibits a greater percentage of data having a residual less than or equal to 3 dB(A) or in the range between 3 and 6 dB(A).

Table 8. Statistics for the wide band (20 to 20,000 Hz) residual equivalent continuous sound pressure level

Equivalent continuous sound pressure level	Data percentage (%)			
	≤ 3 dB(A)	3-6 dB(A)	6-9 dB(A)	> 9 dB(A)
L_{Aeq} ISO 9613 method	20.6	14.3	12.7	52.4
L_{Aeq} proposed method	20.6	17.5	12.7	49.2
L_{Aeq} proposed method (atypical data excluded)	25.0	21.2	15.4	38.5

Source: own elaboration

Through an exhaustive exercise involving both measurement and analysis, a semiempirical model is proposed for calculating sound pressure levels at various distances for noise originating from emission sources which best predicts reality or is closer to it than current standards. The proposed model can be used for predicting noise originating from a noise emission source at distances of up to 64 m, *i.e.*, significantly improved compared with those obtained to date using the method established in standard ISO 9613 Part 2.

Moreover, the study provides a semiempirical focus that combines theoretical modeling with empirical data to solve the problem of noise propagation based on observations and measured data. Theoretical modeling seeks to understand the phenomenon of noise propagation by systematically applying the laws that govern it. However, it is impossible to perfectly capture all the real details regarding the behavior of the process using only mathematical equations. Therefore, empirical modeling uses information obtained experimentally to represent some relationships that have not yet been adequately discovered using mathematical functions, particularly when the process is extremely complex.

New focuses were used for several specific parameters in noise propagation with the aim of improving the prediction of sound pressure levels or to bring them closer to the actual situation. The reality is very complex, and therefore, it is difficult to find an analytical solution for the propagation of noise. The proposed model offers a compromise between simplicity and accuracy in the prediction of sound pressure levels associated with a noise emission source.

The residual sound pressure level obtained using the proposed propagation model varies between -32.4 and 32.7 dB(A), with a median of -1.4 dB(A). The wide band (20 to 20,000 Hz) equivalent continuous sound pressure level varies between -19.7 and 12.9 dB(A), with a median of -5.7 dB(A).

Conclusions

Unlike what was published by K. Attenborough [4], the standard method established in ISO 9613 Part 2 does not have reasonable accuracy for calculating sound attenuation during propagation in free field to predict sound pressure levels. As may be clearly observed from the data, the accuracy level of the method described in standard ISO 9613 Part 2 is not high. The maximum allowable difference between the simulated levels and the measured levels was set at 3 dB(A) [22]. For all types of stabilities, frequencies, and measurement points, 23.2 % of the data exhibit a residual that is less than or equal to 3 dB(A). For a wideband equivalent continuous sound pressure level, 20.6 % of the data exhibit a residual that is equal to or less than 3 dB(A). The correlation coefficient between the results generated by the model and the measured data is 0.81.

Other than the obvious deviations between of ISO 9613-2 calculation results and noise measurements, the other striking feature from the comparison is the lack of detail, which prevents an interpretation of the outdoor sound propagation mechanisms which come into play.

The proposed propagation model exhibits a lower standard deviation, lower error (both standard and absolute), and a greater correlation coefficient, than those of the method contained in standard ISO 9613 Part 2.

A statistically significant relationship exists between these variables at the 95 % confidence level. The standard error for the proposed prediction method is 11.4 dB(A), and the absolute average error is 9.1 dB(A). The correlation coefficient of the proposed model is 0.87.

According to the results obtained through the experimental program, the residual sound pressure level given by the proposed model is small compared to those obtained using the method established in standard ISO 9613 Part 2, particularly considering the distances involved. It may be concluded that the proposed acoustic prediction model is quite satisfactory.

As mentioned earlier, the atmospheric stability must be considered for both the measurements and the sound modeling associated with the noise emission sources. The proposed model takes the atmospheric stability into account using both stability classes and horizontal and vertical propagation coefficients.

The proposed model has more parameters than the basic components of the model established in standard ISO 9613 Part 2. Most of the model's entry parameters are similar to those of the standard, whereas others have been made more complex, resulting in a much more precise model. The basic parameters of the model include the distance, height and sound power level of the noise source; the wind direction and speed; and the air temperature and humidity. Some of the more complex data used in the model includes the ground absorption, the atmospheric stability, and the directionality factor.

Some of these parameters are more influential than others. The main parameter is the atmospheric stability. The second is wind speed. Both the atmospheric stability and the wind speed play important roles in the propagation of sound from noise emission sources.

The physical processes present in the atmosphere cannot be studied separately because they interact with each other. Therefore, all such parameters must be studied simultaneously to avoid an underestimation or overestimation of the sound pressure levels. Indeed, attenuation due to atmospheric stability includes several parameters that have already been considered in other forms of attenuation.

This study demonstrates that the prediction model established in standard ISO 9613 Part 2 exhibits deficiencies in estimating the noise generated by a noise source. The variations in sound pressure levels are largely due to changes in weather conditions.

The proposed model is well-defined and relatively easy to use. It may be considered a “submodule” or a variation of model ISO 9613 Part 2. If the suggested adjustments are applied to the model proposed in standard ISO 9613 Part 2, then the estimated sound pressure levels exhibit a much better fit with measured levels.

It is necessary to continue advancing the in the development of models for predicting the propagation of noise from fixed noise sources in which meteorological and acoustic measurements can be simultaneously covered in an accurate and verifiable manner in order to allow the analytical solution of this problem. In addition, it is necessary to verify the performance of the noise prediction model proposed in other fixed sources of noise emissions in order to have sufficient experimental data.

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