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UPDATED LATERAL ATTENUATION IN FAA'S INTEGRATED NOISE MODEL

G.G. Fleming*, J. Burstein*, A.S. Rapoza*, D.A. Senzig*, J.M. Gulding, T.L. Connor****

* United States Department of Transportation John A. Volpe National Transportation Systems Center Acoustics, Kendall Square, MA 02142, Cambridge, United States Of America

** United States Department of Transportation; Federal Aviation Administration, Office of Environment and Energy, AEE-120, 800 Independence Avenue, 20591, Washington DC, United States Of America

Email: fleming@volpe.dot.gov

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ABSTRACT

The lateral attenuation algorithm in the Federal Aviation Administration's (FAA) Integrated Noise Model (INM) has historically been based on the two regression equations described in the Society of Automotive Engineers' (SAE) Aerospace Information Report (AIR) 1751. These equations, which together represent a single relationship developed from measured data for 1960s and 1970s aircraft with low-bypass ratio jet engines, are applied equally in INM to the entire aircraft fleet. Further, these equations cannot take into account the effects of propagation over acoustically hard terrain, such as water. Consequently, in 1997 the INM development team initiated the task of revising the lateral attenuation algorithm within the model. The primary component of the revised algorithm is an entirely new methodology for taking into account ground effects. The methodology, which is based upon a newly-compiled spectral data base, along with the physical acoustics model of Embleton, Piercy and Daigle, will exist in INM as a library of regression equations. As such, this approach will offer the accuracy and flexibility of a pure physical acoustics model, coupled with relatively modest computer runtimes. This paper documents the scientifically-founded and experimentally-validated approach to computing ground effects, which is slated for inclusion in the INM.

1 - INTRODUCTION

The lateral attenuation algorithm in the Federal Aviation Administration's (FAA) Integrated Noise Model (INM) has historically been based on regression equations described in the Society of Automotive Engineers' (SAE) Aerospace Information Report (AIR) 1751 [1]. This AIR contains two equations, one used to compute attenuation from air-to-ground propagation (for airborne aircraft) and one for computing attenuation from ground-to-ground propagation (for aircraft taxiing, landing or in takeoff-ground roll). Up to and including the INM Version 6 [2,3], these two field-measurement-based (empirical) equations have been used for computing lateral attenuation for all commercial aircraft within the model. Similar empirical equations have been used for military aircraft in the INM.

Released in 1981, SAE AIR 1751 is based on data that were compiled in the 1960s and 1970s. The majority of the aircraft represented in this data set were equipped with low-bypass ratio jet engines. In addition, a single type of jet aircraft, the older Boeing Model 727-100 dominated the data set. It is generally recognized by the technical community that the SAE-based lateral attenuation algorithm within the INM is the single-biggest ***acoustic*** weakness in the model for the following two reasons: (1) the algorithm, which represents a single relationship developed from data dominated by one type of aircraft, is applied equally to the entire fleet; and (2) the algorithm cannot account for propagation effects over acoustically hard terrain, a major weakness at airports in coastal areas. Consequently, in

1997 the INM development team initiated the task of revising the lateral attenuation algorithms within the model.

At the most fundamental level, the lateral attenuation of aircraft noise comprises two basic physical phenomena, engine installation effects and ground effects. Engine installation effects, which are implicit in the current SAE AIR 1751 algorithms, may account for sound reflections off of the aircraft wings and fuselage, and sound shielding primarily from the fuselage. Ground effects account for the introduction of an impedance boundary, in this case the ground surface, into a given aircraft-to-receptor geometry.

In many cases, engine installation effects are thought to be small relative to ground effects. In fact, in the soon-to-be released updated version of the United States Air Force's NOISEMAP computer program for assessing noise impact in the vicinity of military installations, engine installation effects are neglected and lateral attenuation is based solely on ground effects [4]. However, the data that were used in the development of SAE AIR 1751 seem to indicate that for some commercial jet aircraft (e.g., the Boeing Model 727), engine installation effects may be important, depending upon source-to-receptor geometry. A recent study conducted at Boston's Logan International Airport [5] indicates that the engine installation effect is directly related to where the engine is located on the aircraft. Specifically, for aircraft with tail-mounted engines, e.g., the B-727 and the DC9/MD80, the engine installation effects agree fairly well with the relationships in SAE AIR 1751. However, for many of the more modern aircraft with wing-mounted engines, e.g., the B-737 with CFM series engines, B-757 and A320, the engine installation effect is very small and possibly negligible. The manner in which engine installation effects will be accounted for in the INM is under further investigation. Consequently, this paper focuses on the ground effect phenomenon, and the method that will be used to account for it within the INM.

The new approach for computing ground effects in the INM, presented herein, is founded in acoustic theory and has undergone rigorous laboratory and field tests. A recently completed field study at Denver International Airport shows that predicting ground effects using the theoretical model described herein offers a substantial improvement over predicting ground effects with the equations currently in SAE AIR 1751 [6]. On average, the improvement is as large as 5 dB at a source-to-receptor elevation angle of three degrees. The above-mentioned Boston-Logan study also validates the use of these theoretically-based ground effect algorithms.

2 - SPECTRAL CLASSES

The starting point in any empirical model such as the INM is a reference database. To accurately account for ground effects, the traditional noise-power-distance (NPD) database in the INM had to be supplemented with frequency-based data at some level of detail. This requirement is due to the fact that ground effects are a relatively complex function of frequency.

Since spectral data were not available for the entire aircraft fleet within the INM [7], and since initial sensitivity testes indicated that maintaining separate spectral data for each aircraft would result in a negligible improvement in computational accuracy, the approach of grouping similar spectra seemed to offer a logical compromise. These like spectra are referred to herein as a *spectral class*.

The INM contains 72 unique spectral classes. In total, there are 31 classes for departure, 34 classes for approach, and 7 classes for level flyover (applicable to helicopters only). As an example, the INM aircraft included within Departure Spectral Class 101 are the 727, 737 and DC-9 with the older Pratt and Whitney JT8D series engines, the DC10 with the General Electric CF6 series engines, L1011 with the Rolls Royce series RB2112 engines, and the F100 with the TAY620 and TAY 650 series engines.

3 - GROUND EFFECTS MODEL

The ground effects model documented by Tony **E**mbleton, Joe **P**iercy and Giles **D**aigle (the EPD Model) of the National Research Council (NRC) of Canada is the scientific foundation for the updated ground effects equations slated for inclusion in the INM. The EPD model is documented extensively in References 8 through 10, and is not discussed further herein.

The library of spectral class data provided the reference database for computing ground effects. It was determined that implementing the EPD model directly into the INM would dramatically increase run-times by a factor deemed unacceptable. Tests showed that fitting a series of regression equations to the ground effects data would result in more reasonable run-times. For the regression analysis, the spectral data along with the EPD physical acoustics model discussed above were used in tandem to develop a comprehensive ground-effects database. The specific methodology utilized to develop the database is discussed extensively in Reference 11, but in general involved successive exercising of the EPD model in tandem with the spectral class data for thousands of source-to-receptor geometries. The result of the process is a ground effects database (i.e., a table of ground effects values), existing as a function of source-to-receptor distance and reflection angle for each of two ground conditions, acoustically soft and acoustically hard ground.

4 - REGRESSION ANALYSIS

As a result of extensive analysis, it was determined that the ground effects database was best represented by a library of regression equations. The general form of the regression equation was different for acoustically soft and acoustically hard ground. The functional form of the final regression used for acoustically soft ground is as follows:

$$\begin{aligned} A_{Soft} = \; & FF_{ADJ} + \left\{X_1 + X_2\,(.033d) + (X_3)\,(.033d)^2\right\} + \\ & \left\{X_4 + X_5\,(.033d) + (X_6)\,(.033d)^2\right\}\{0.1\alpha\}^Y + \\ & \left\{X_7 + X_8\,(.033d) + (X_9)\,(.033d)^2\right\}\{0.1\alpha\}^2 \quad dB\,(A) \end{aligned} \tag{1}$$

where:

- A_{Soft} is the total ground effect in decibels (A-weighted) for a pure acoustically soft ground geometry;
- FF_{ADJ} is the free-field adjustment term (dB(A));
- X_N and Y are empirically-derived regression coefficients;
- d is the source-to-receptor ground distance (m); and
- α is the reflection angle (degrees).

As an example, Figure 1 presents the original data in the ground effects database (directly from the EPD model) along with the computed regression for propagation over acoustically soft ground for departure spectral class 101 and a distance of 1000 m. This comparison can be considered typical.

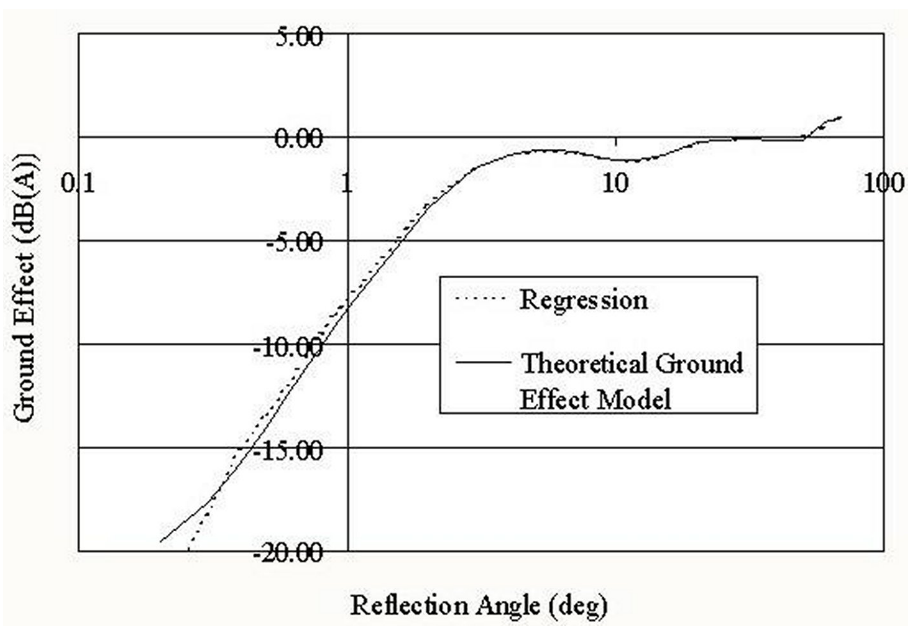

Figure 1: Comparison of model output and regression; departure spectral class 101; distance=1000 m; acoustically soft ground.

An exponential relationship of the following form was used for the acoustically hard ground regression equation:

$$A_{hard} = FF_{AFJ} + \left(Q + \left(\,A/\left(1 + e^{(B0+B1\log(\alpha))}\right)\right)\right) * (C0 + C1 * d) \quad dB\,(A) \tag{2}$$

where:

- A_{hard} is the total ground effect in decibels (A-weighted) for a pure acoustically hard ground geometry;

- FF_{ADJ} is the free-field adjustment term (dB(A));
- Q, A, B0, B1, C0, and C1 are empirically-derived regression coefficients;
- d is the source-to-receptor ground distance (m); and
- α is the reflection angle (degrees).

As an example, Figure 2 presents the original data in the ground effects database (directly from the EPD model) along with the computed regression for propagation over acoustically hard ground for departure class 101 and a distance of 1000 m. This comparison can be considered typical.

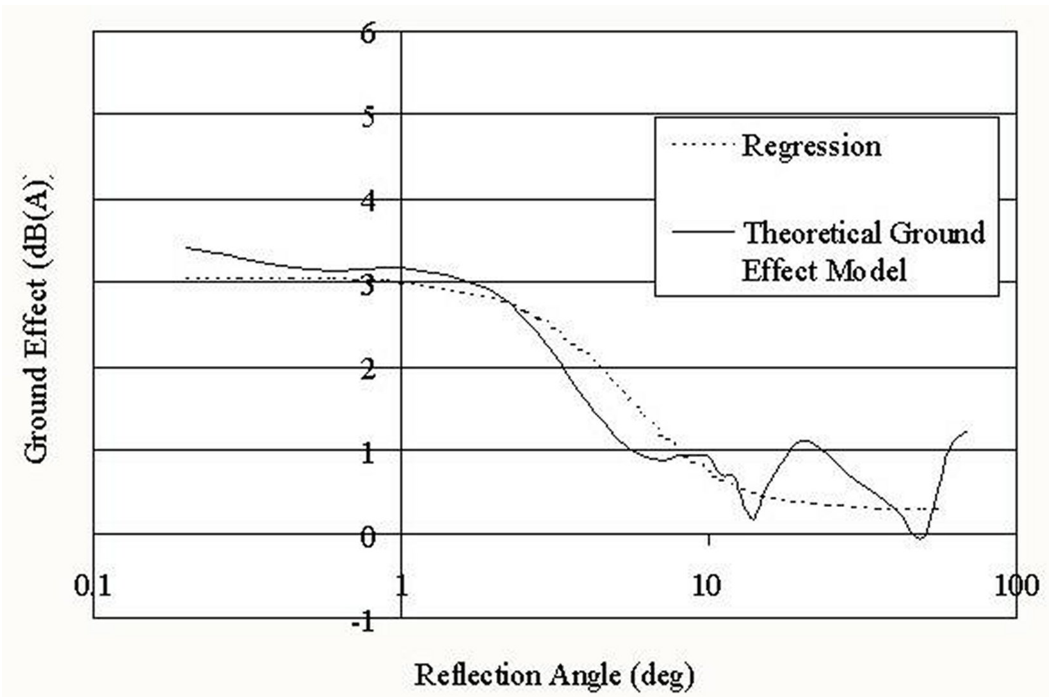

Figure 2: Comparison of model output and regression; departure spectral class 101; distance=1000 m; acoustically hard ground.

5 - MIXED GROUND IMPLEMENTATION

The regression coefficients, along with some notable constraints were implemented in the INM for acoustically soft and hard ground situations. However, many practical modeling situations include propagation over mixed, acoustically soft and hard terrain. Consequently, a methodology was developed to properly account for such situations. The approach decided upon was very similar to that implemented within the Federal Highway Administration's Traffic Noise Model (FHWA TNM ®) [12,13] and is based on the work of Boulanger [14]. Specifically, the acoustically soft-ground and hard-ground effect were apportioned based on a distance-weighted coefficient. This coefficient was computed based on the ground distance associated with the acoustically hard and acoustically soft portion of the ground contained within the so-called Fresnel Ellipsoid. The Fresnel Ellipsoid is a frequency-dependent function used fairly extensively in acoustics. The nature of the function is such that the ellipsoid effectively widens for lower frequencies and narrows for higher frequencies. The relationship is made to be consistent with the relationship between the frequency of a sound and its wavelength.

In addition, a suite of utility programs was developed to facilitate the automatic input of United States Geological Survey (USGS) 1:100,000-scale digital line graph hydrographic files. These files contain the ground cover information necessary for automatically computing ground effects for a mixed ground scenario.

Within the INM, the ground projection from the microphone to a particular flight segment is effectively overlaid on the ground cover data. If the projection traverses acoustically soft or hard ground only, the appropriate ground effects regression equation is evaluated. If the projection traverses acoustically mixed grounds, the INM determines the appropriate percentage of acoustically soft or hard ground distances.

6 - CONCLUSION

This paper summarizes a scientifically based, experimentally validated methodology for computing ground effects. The methodology has been implemented in a research version of the FAA's INM. It results in an improvement in the model's predictive accuracy, especially at small reflection angles. Further, it provides the INM user with the ability to take into account the effects of an acoustically hard surface such as water, including the effects of mixed, acoustically soft and hard ground surfaces, a capability never before available in the model. Recent field studies have shown the approach to agree well with measured data. Additional in-situ field tests which are currently in the planning stages will provide further validation of the methodology, and will help provide a better understanding of the engine installation effect.

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