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[N465] Use of One-Third Octave-Band Spectral Data in Community Noise Models

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ABSTRACT

Airport noise planning models typically use guidance contained in the Society of Automotive Engineers (SAE), Airspace Information Report (AIR), SAE-1845, titled "Procedure for the Calculation of Airplane Noise in the Vicinity of Airports [1]. This document shares material similar to that in European Civil Aviation Conference (ECAC) Doc 29 [2] and International Civil Aviation Organization (ICAO) Circular 205 [3]. All three documents define a noise source and propagation that compute noise exposure for a reference terrain of acoustically absorptive, soft ground and a single reference atmosphere considered to be representative of average worldwide airport conditions. Detailed source data are used to propagate noise relative to this reference atmosphere through the use of noise-power-distance (NPD) databases. One-third octave-band data are not inherently required in noise models of this type. Proposed updates to the above guidance documents allow for the modeling of airport-specific atmospheric conditions and terrain. Adjusting for these local conditions requires the addition of spectral data to community airport noise models. This paper proposes to develop these spectral data as a natural extension to the guidance already specified in References 1-3. The authors describe the derivation of spectral class data for the Federal Aviation Administration's (FAA) Integrated Noise Model (INM), several validation and verification procedures used for spectral class data, and recommend updated language to the guidance given in References 1-3 to account for one-third octave- band data.

BACKGROUND

Traditionally, community noise models that focus on aircraft noise impact modeling have been based on the guidance provided in References 1 through 3. The guidance includes usage of NPD data and interpolation/extrapolation from those data to determine levels at specific distances. In the context of aircraft noise modeling, NPD data reflect the operations of aircraft in various states, accounting for variations due to power setting, flight mode (arrival or departure), landing gear state (deployed or retracted) as well as airframe noise. The additional capabilities afforded by the incorporation of one-third octave-band data in community noise models warrant the added burden associated with data collection, reduction and analysis. Specifically, the inclusion of spectral data allows for the following enhancements to the traditional SAE-1845 modeling methodology: (1) calculation of atmospheric absorption effects (atmospheric absorption effects) over the propagation distance; (2) calculation of ground attenuation (ground effects) due to acoustically hard and/or mixed ground types beneath the propagation path; and (3) calculation of line-of-sight blockage and/or "barrier" effects (barrier effects) between source and receiver. Research indicates community noise models that account for these effects better match measured data [4,5,6].

The FAA's INM, Version 6.0 [7,8], released in September 1999, includes the addition of aircraft spectral class data and the capability to evaluate atmospheric absorption effects. The INM's database includes data for a large percentage of the commercial aircraft fleet.[a] Whereas one-third octave-band data are available for many of the aircraft certified within the last decade, such data are not readily available for many of the older jet aircraft, nor for a significant percentage of propeller-driven aircraft. Further, similar data for military aircraft are difficult to obtain. Accordingly, to incorporate atmospheric effects, the INM development team included the concept of a spectral class, or grouping of aircraft with similar spectral characteristics, in Version 6.0. This concept is further investigated below.

Research versions of the INM incorporate the calculation of ground effects for hard-/mixed-ground types utilizing the spectral class data. Inclusion of these calculations in official release versions of the model is expected upon final approval of an updated SAE-AIR-1751 [9] by the SAE Aircraft Noise Committee (A-21). Development on the inclusion of barrier effects in the model is ongoing.

SPECTRAL CLASS DEVELOPMENT

A detailed example of the spectral class development process is outlined in Appendix D of Reference 7. The spectral class development process is iterative in that the initial selection of members of a spectral class may fail predetermined criteria. In this case, spectra are eliminated and/or regrouped and the process is repeated. The first step in deriving a spectral class is the grouping of aircraft considered similar based on the combination of the aircraft and engine types. Considerations for grouping aircraft include airframe, engine type, number of engines, engine location, and engine bypass ratio.

After grouping the aircraft by similar aircraft/engine types, we proceed to Step #2. Step 2 is a visual inspection of the potential spectral class data. Each zero-weighted spectrum measured at the time of A-weighted Maximum Sound Level (L_{ASmx}) is graphed on a single chart and visually inspected for similarity. Criteria for "similarity" include the general spectral shape as well as the relative location of any tones below 1000 Hz. To aid in this inspection, the spectra are normalized to a value of 70.0 dB at 1,000 Hz, along with a *proposed* spectrum that is considered representative of the overall spectral class. The actual spectral levels are de-referenced and only the relationship between levels in individual bands is preserved, i.e., the spectral shape. The proposed, representative spectrum is the weighted (across the entire fleet, based on the number of annual operations per aircraft type), arithmetic average of the individual, one-third octave-band spectral data. Figure 1 illustrates a representative spectrum and the individual spectra used in its derivation.

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[a] The INM Version 6.1 database contains over 50% fleet coverage of Boeing aircraft and almost 40% fleet coverage for Airbus aircraft, aircraft registration current as of 6 January 2003.

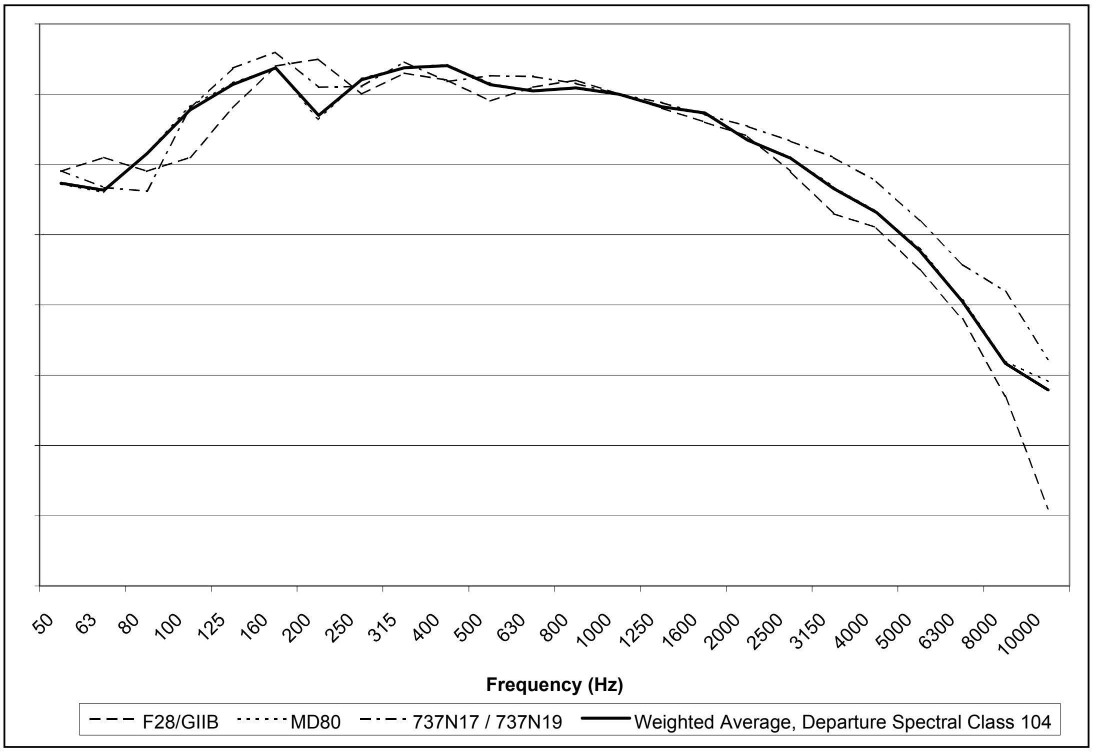

Figure 1. Spectral Class Data

Step #3 involves verifying the suitability of the proposed spectral class. To accomplish this task individual spectra and associated representative spectra are subjected to acoustical sensitivity tests that require one-third octave-band spectral data. An example of the sensitivity tests is an algorithm that calculates ground effects for a source-to-receiver separation distance of 1000 m (3,278 ft). Specifically, the EPD Model [10,11,12] calculates the ground effects for propagation over ground with an effective flow resistivity of 150 cgs/rayls (acoustically soft ground). Calculated ground effects, as a function of source-to-receiver elevation angle, are investigated for both the representative spectral class and individual spectra. The proposed spectral class is considered to adequately represent the individual spectra if the ground effects curves for each aircraft consistently fall within +/- 1 dB of the spectral class ground effects for all elevation angles. If determined to be representative, the spectral class is utilized for modeling propagation effects for all the individual aircraft used to derive the data. If, however, the spectral class does not meet the +/- 1 dB criteria, the spectral class development process is reinitiated using a different combination of spectra.

SPECTRAL CLASS VALIDATION AND VERIFICATION

In addition to the validation/verification during the development of spectral class data using the EPD ground effects model, there has been further examination of the sensitivity of the use of spectral classes in the calculation of atmospheric absorption effects. Specifically, recent manufacturer-provided NPD data, submitted for inclusion in the INM, were examined to test the sensitivity of spectral class data. These data, which include associated zero-weighted spectra measured at the time of L_{ASmx}, were derived by a process consistent with the integrated procedure outlined in FAR Part 36 (FAR36) [13]. We made a comparison of NPD data evaluating the differences between manufacturer data and those derived utilizing spectral classes.

The validation/verification process includes data representative of four modern jet aircraft. Spectral data for both approach and departure operations were utilized for each aircraft. Manufacturer-provided and spectral class spectra were propagated using guidance found in the FAR36 simplified procedure to ten standard distances: 61m (200 ft.), 122m (400 ft.), 192 m (630 ft.), 305 m (1,000 ft.), 610 m (2,000 ft.), 1,220 m (4,000 ft.), 1,920 m (6,300 ft), 3,050 m (10,000 ft.), 4,877 m (16,000 ft.) and 7,620 m (25,000 ft.). The spectra were propagated to these distances through four unique, homogeneous atmospheres: 15EC (59EF), 70% relative humidity (RH); 25EC (77EF), 70% RH; 15EC (59EF), 55% RH; and 25EC (77EF), 55% RH. Figure 2 presents a summary of all corrected data, for the four aircraft, for both the L_{ASmx} and Sound Exposure Level (L_{AE}) noise descriptors. The figure presents differences in sound level, manufacturer-provided data minus spectral class data.

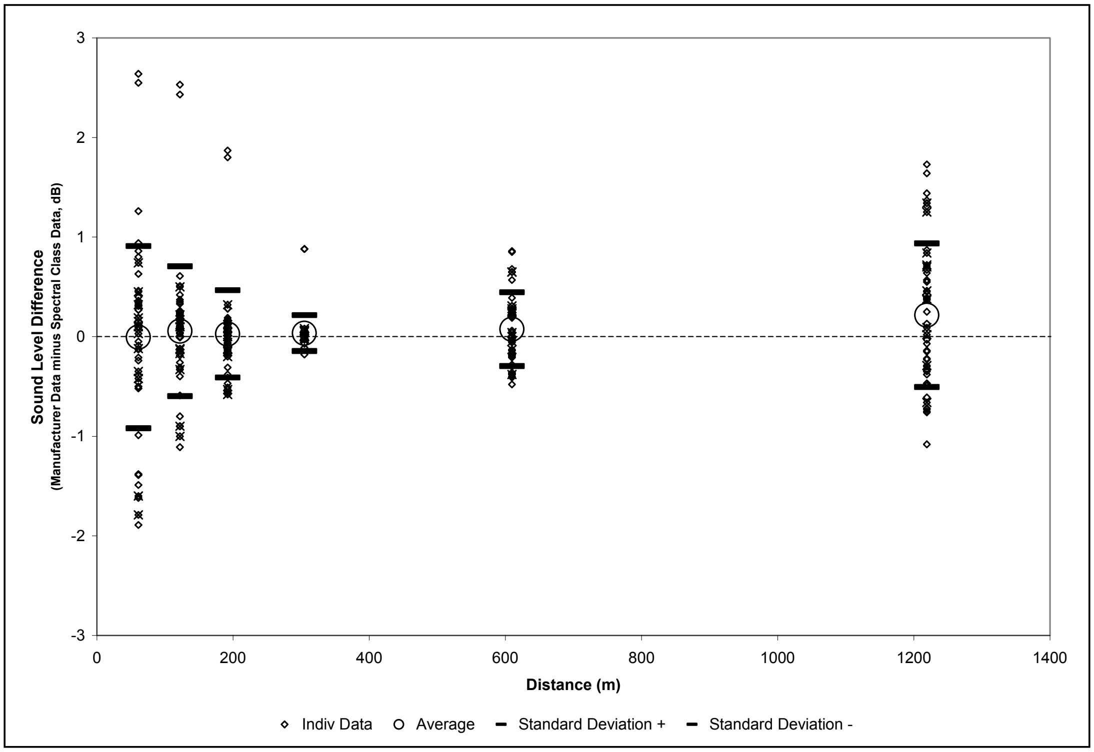

Figure 2. Summary of Sound Level Differences, Manufacturer Minus Spectral Class

Figure 2 illustrates excellent agreement between spectral class and manufacturer-provided data (average distance-based difference within 0.3 dB; all data generally within 3 dB; standard deviation less than 1 dB) out to a distance of 1,220 m (4,000 ft.). These values are 1.2, 5 and 3 dB, respectively, out to propagation distances of 7,620 m (25,000 ft.), the largest slant distance typically represented in NPD data. This validation/verification process also illustrates that the use of spectral class data, for the calculation of atmospheric absorption effects, is a natural extension of the FAR36 process to account for atmospheric absorption.

UPDATES TO GUIDANCE LANGUAGE

Given the utility demonstrated by the use of spectral class data, the authors recommend that relevant airport noise modeling guidance documents [1 through 3] be updated to reflect the use of one-third octave-band acoustic data. These updates may include a spectral data tiered approach. This tiered approach would reflect that: (1) spectral data may not be available for all aircraft, particularly existing older aircraft; and (2) incorporation of spectral data for all, individual aircraft, may yield only marginally better modeling results, as compared with classes of spectra used to represent many aircraft. The tiered use of spectral data might expand the range of the current guidance, which does not typically include the use of one-third octave-band spectral data, to include detailed spectral data for all aircraft. Between these two extremes is the use of spectral classes, which affords increased computational accuracy with limited effect on computational run-time for airport-wide analyses. To enable the use of spectral data, be it spectral classes or otherwise, in community noise models, the burden is on aircraft manufacturers to collect and provide such data. For spectral classes, the minimal data requirement is the zero-weighted spectrum at time of L_{ASmx} for each NPD state.

SUMMARY

The incorporation of "spectral class" data into community noise models is a logical prerequisite for improving community noise model performance. The authors outline the procedure that will successfully incorporate spectral data and help quantify the effect of its use on model uncertainty. Given the increased capabilities afforded by the use of spectral data, it is also recommended that the appropriate noise modeling guidance documents be updated to reflect the incorporation of spectral data and that models based on this guidance be updated accordingly.

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