Appendix 3

Guidelines for Adjustment of Aircraft Noise Levels for the Effects of Background Noise

1.0 Introduction:

1.1 The following information is provided as guidance material on procedures for adjusting measured aircraft noise levels for the effects of background noise.

1.2 The presence of background noise during aircraft noise certification tests can influence measured aircraft sound levels, and in some cases, obscure portions of the spectral time history used to obtain EPNL values. Adjustment procedures must include the following components:

- Testing to determine which, if any, portions of the spectral time history are obscured.
- Adjusting unobscured levels to determine the aircraft sound levels that would have been measured in the absence of background noise.
- Replacing or reconstructing obscured levels by frequency extrapolation, time extrapolation, or by other means.

1.3 A list of definitions for terms used in this appendix is provided in Section 2.0. Although some of the terms have generally accepted meanings, the specific meanings as defined apply herein.

1.4 A detailed, step-by-step procedure is presented in Section 3.0, including equations and descriptions of time and frequency extrapolation methods (3.2.10). Other procedures may be used provided that they have been approved by the certificating authority.

1.5 General considerations, which apply to any background noise adjustment procedure, are listed in Section 4.0, including requirements and limitations (4.1) and other special considerations (4.2 through 4.4).

2.0 Definitions:

For purposes of this appendix, the following definitions apply:

- **adjusted (level):** a valid one-third-octave band level, which has been adjusted for measurement conditions, including:
  1.) The energy contribution of pre-detection noise; and
  2.) Frequency-dependent adjustments such as system frequency response, microphone pressure response and free-field response, and windscreen incidence-dependent insertion loss.

- **ambient noise:** the acoustical noise from sources other than the test aircraft present at the microphone site during aircraft noise measurements. Ambient noise is one component of background noise.

- **background noise:** the combined noise present in a measurement system from sources other than the test aircraft, which can influence or obscure the aircraft noise levels being measured. Typical elements of background noise include (but are not limited to): ambient noise from sources around the microphone site; thermal electrical noise generated by components in the measurement system; magnetic flux noise ("tape hiss") from analog tape recorders; and digitization noise caused by quantization error in digital converters. Some elements of background noise, such as ambient noise, can contribute energy to the measured aircraft noise signal while others, such as digitization noise, can obscure the aircraft noise signal.

- **energy-subtraction:** subtraction of one sound pressure level from another, on an energy basis, in the form:

$$10\log_{10}\left[10^{(L_A/10)} - 10^{(L_B/10)}\right]$$

  Where L_A and L_B are two sound pressure levels in decibels, L_B being the value subtracted from L_A.

- **frequency extrapolation:** a method for reconstruction of high frequency masked data, based on unmasked data in a lower-frequency one-third-octave band from the same spectrum. (See 3.2.10.a.)

- **high frequency bands:** the twelve bands from 800 Hz through 10 kHz inclusive. (See also "low frequency bands".)

- **LGB (Last Good Band)**: in the adjustment methodology presented in Section 3.0, for any aircraft one-third-octave band spectrum, the highest-frequency unmasked band within the range of 630 Hz to 10 kHz inclusive, below which there are no masked high frequency bands

- **low frequency bands:** the twelve bands from 50 Hz through 630 Hz inclusive. (See "high frequency bands".)

- **masked (band):** within a single spectrum, any one-third-octave band containing a masked level.

- **masked (level):** any one-third-octave band level which is less than or equal to the masking criterion for that band. When a level is identified as being masked, the actual level of aircraft noise in that band has been obscured by background noise and cannot be determined. Masked levels can be reconstructed using frequency extrapolation, time extrapolation, or other methods.

- **masking criteria:** the spectrum of one-third-octave band levels below which measured aircraft sound pressure levels are considered to be masked or obscured by background noise. Masking criteria levels are defined as the greater of:
  1.) pre-detection noise +3 dB; or
  2.) post-detection noise +1 dB.

- **post-detection noise:** the minimum levels below which measured noise levels are not considered valid. Usually determined by the baseline of an analysis "window", or by amplitude non-linearity characteristics of components in the measurement and analysis system. Post-detection noise levels are non-additive, i.e., they do not contribute energy to measured aircraft noise levels.

- **pre-detection noise:** any noise which can contribute energy to the measured levels of sound produced by the aircraft, including ambient noise present at the microphone site and active instrumentation noise present in the measurement, recording / reproducing, and analysis systems.

- **reconstructed (level):** a level, calculated by frequency extrapolation, time extrapolation, or by other means, which replaces the measured value for a masked band.

- **time extrapolation:** a method for reconstruction of high frequency masked data, based on unmasked data in the same one-third-octave band, from a different spectrum in the time-history. (See 3.2.10.b.)

- **valid** or **unmasked (band):** within a single spectrum, any one-third-octave band containing a valid level.

- **valid** or **unmasked (level):** any one-third-octave band level which exceeds the masking criterion for that band.

3.0 Background noise adjustment procedure

3.1 Assumptions:

- A typical aircraft spectrum measured on the ground contains one-third-octave band levels which decrease in amplitude with increasing frequency. This characteristic high frequency roll-off is due primarily to the effects of atmospheric absorption.

- A typical electronic instrumentation floor spectrum contains one-third-octave band levels which increase in amplitude with increasing frequency.

- Due to the aforementioned assumptions, as the observed frequency is increased within a one-third-octave band aircraft spectrum, and once a band becomes masked, all subsequent higher-frequency bands will also be masked. This allows the implementation of a "Last Good Band" (LGB) label to identify the frequency band above which the bands in a spectrum are masked.

- If, on occasion, a valid level occurs in a band of higher frequency than LGB, its presence will most likely be due to small variations in the pre-detection levels, and/or because the levels of the measured aircraft one-third-octave band spectrum are close to the levels of the background noise in general, and therefore its energy contribution will not be significant (This assumption is only valid in the absence of significant aircraft-generated tones in the region of masking). Therefore, the possibility of a level being valid in a band of higher frequency than LGB may be ignored. Applicants who prefer to implement algorithms for identifying and handling such situations may do so, but no procedure may be used without prior approval from the certificating authority.

3.2 Step-by-step description:

3.2.1 Determination of pre-detection noise: a time-averaged one-third-octave band spectrum of pre-detection noise levels for each test run (or group of runs occurring during a short time period) should be obtained by recording and analyzing ambient noise over a representative period of time (at least 30 seconds in duration). Care should be taken to ensure that this ambient noise sample reasonably represents that which is present during measured aircraft runs. In recording ambient noise, all gain stages and attenuators should be set as they would be during the aircraft runs to ensure that the instrumentation noise is also representative. If multiple gain settings are required for aircraft noise measurements, a separate ambient sample should be recorded at each setting used.

3.2.2 Determination of post-detection noise: a one-third-octave band spectrum of post-detection noise levels should be determined as a result of testing (or from manufacturer's specifications), for each measurement / analysis configuration used (including different gain and / or sensitivity settings). Minimum valid levels may be determined on the basis of display limitations (e.g., blanking of the displayed indication when levels fall below a certain value), amplitude non-linearity, or other non-additive limitations. In cases where more than one

component or stage of the measurement / analysis system imposes a set of minimum valid levels, the most restrictive in each one-third-octave band should be used.

3.2.3 Testing of pre-detection noise versus post-detection noise: the validity of pre-detection noise levels must be established before these levels can be used to adjust valid aircraft noise levels. Any pre-detection noise level which is equal to or less than the post-detection noise level in a particular one-third-octave band should be identified as invalid, and therefore should not be used in the adjustment procedure.

3.2.4 Determination of masking criteria: once the pre-detection noise and post-detection noise spectra are established, the masking criteria can be identified. For each one-third-octave band, compare the valid pre-detection noise level +3 dB with the post-detection noise level +1 dB. The highest of these levels is used as the masking criterion for that band. If there is no valid pre-detection noise level for a particular one-third-octave band, then the post-detection noise level +1 dB is used as the masking criterion for that band. The 3 dB window above pre-detection levels allows for the doubling of energy which could occur if an aircraft noise level were equal to the pre-detection level. The 1 dB window above the post-detection levels allows for a reasonable amount of error in the determination of those levels.

3.2.5 Identification of masked levels: each spectrum in the aircraft noise time-history can be evaluated for masking by comparing the one-third-octave band levels against the masking criteria levels. Whenever the aircraft level in a particular band is less than or equal to the associated masking criterion, that aircraft level is considered masked. A record must be kept of which bands in each spectrum are masked.

3.2.6 Determination of Last Good Band: for each ½-second spectral record, determine the highest-frequency unmasked one-third-octave band ("Last Good Band" or "LGB") by starting at the 630 Hz band and incrementing the band number (increasing frequency) until a masked band is found. At that point, set LGB for that spectral record equal to the band below the masked band. The lowest-frequency band that can be identified as LGB is the 630 Hz band. In other words, if both the 630 Hz band and the 800 Hz band are masked, no reconstruction of masked levels may be performed for that spectrum, and the thirteen bands between 630 Hz and 10 kHz inclusive should be left as-is and identified as masked. Per the masking limits specified in Section 4.2.1 of this Appendix, such a spectrum is not valid for calculation of EPNL.

3.2.7 Adjustment of valid levels for background noise: in each ½-second spectrum, for each valid band up to and including LGB, perform an energy-subtraction of the valid pre-detection level from the valid measured level in the aircraft noise time-history:

$$10\log_{10}\left[10^{(L_{AIRCRAFT}/10)} - 10^{(L_{PRE-DETECTION}/10)}\right]$$

Energy-subtraction should be performed on **all** valid one-third-octave band noise levels. For any one-third-octave band where there is no valid pre-detection noise level, no energy-subtraction may be performed, i.e., this adjustment cannot be applied when either the measured aircraft noise time-history level or the pre-detection noise level is masked.

3.2.8 Adjustment of valid levels for measurement conditions: before any reconstruction can be done for masked levels, valid levels which have been adjusted for the presence of pre-detection noise must also then be adjusted for frequency-dependent adjustments such as: system frequency response, microphone pressure response and free-field response, and windscreen incidence-dependent insertion loss. These adjustments can not be applied to masked levels.

3.2.9 Reconstruction of low frequency masked bands: for cases where a single masked low frequency one-third-octave band occurs between two adjacent valid bands, the masked level can be retained, or the adjusted levels of the adjacent valid bands may be arithmetically averaged, and the averaged level used in place of the masked level. If the average is used, the level should be categorized as reconstructed. However, if masked low frequency bands are found adjacent to other masked low frequency bands, these masked levels should be retained and remain categorized as masked. The procedure presented in this Appendix does not provide for any other form of reconstruction for masked low frequency bands.

3.2.10 Reconstruction of levels for masked high frequency bands: frequency extrapolation and time extrapolation are the methods used to reconstruct masked one-third-octave band levels for bands at higher frequencies than LGB for each spectral record. One-third-octave band atmospheric absorption coefficients (in either dB per 1000 feet, or as used in the example below, dB per 100 m) must be determined before such reconstruction of masked band levels can be performed. Note that noise emission coordinates must also be calculated for each record before reconstruction is performed, since the procedure is dependent on propagation distance.

3.2.10.a For a spectrum where LGB is located at or above the 2 kHz one-third-octave band, use the **frequency extrapolation** method. This method reconstructs masked high frequency bands starting with the level associated with LGB (in the same spectrum). The levels for all bands at higher frequencies than LGB must be reconstructed using this method. Any frequency-extrapolated levels should be categorized as reconstructed. Reconstruct the level for the masked bands using the following equation:

$$Lx_{i,k} = L_{j,k} + a_j \times \frac{SR_k}{100} - a_{j_{REF}} \times \frac{60}{100} + 20\log_{10}\frac{SR_k}{60} + a_{i_{REF}} \times \frac{60}{100} - a_i \times \frac{SR_k}{100} + 20\log_{10}\frac{60}{SR_k}$$

Which can be reduced to:

$$Lx_{i,k} = L_{j,k} + \left[a_j - a_i\right] \times \frac{SR_k}{100} + \left[a_{i_{REF}} - a_{j_{REF}}\right] \times \frac{60}{100}$$

Where:

i	is the masked band to be extrapolated
k	is the record of interest
j	is the Last Good Band (LGB) in record k

$Lx_{i,k}$ is the frequency-extrapolated level in dB for masked band *i* and spectral record *k*;

$L_{j,k}$ is the level for LGB in record *k* after all test-day adjustments have been applied, including pre-detection noise energy-subtraction, system and microphone adjustments, etc.

a_j is the test day atmospheric absorption coefficient (dB per 100 m) for LGB;

a_i is the test day atmospheric absorption coefficient (dB per 100 m) for band *i*;

$a_{j\,REF}$ is the reference (25°C, 70%RH) atmospheric absorption coefficient (dB per 100 m) for LGB

$a_{i\,REF}$ is the reference (25°C, 70%RH) atmospheric absorption coefficient (dB per 100 m) for masked band *i*

SR_k is the slant range or acoustic propagation distance in meters at the time of noise emission for spectral record *k*, between the aircraft and the microphone.

This procedure is based on the assumption that the aircraft spectrum is "flat" (all high frequency band levels are equal) at a distance of 60 meters under reference conditions (25°C, 70%RH). The process can be conceptualized by means of the following steps:

1. The level for band *j* (the highest-frequency unmasked band in spectral record *k*), which has already been adjusted for measurement conditions, is adjusted for test day propagation effects, to obtain the source level, then for reference propagation to the 60-meter distance from the source.
2. This level is then assigned as the level for all high frequency masked bands (band *i*, band *i*+1, etc.) at a distance of 60 meters.
3. A new source level is determined for each masked high frequency band by removing the associated reference day propagation effects.
4. The extrapolated level that would have been measured on the ground, in the absence of background noise, is determined for each masked high frequency band by adding the test day propagation effects to each of the source levels determined in step 3.

3.2.10.b For a spectrum where LGB occurs at or between the 630 Hz one-third-octave band and the 1.6 kHz band, use the **time extrapolation** method. This method reconstructs a masked band in a spectrum from the closest spectral record (i.e., closest in time) for which that band is valid. The levels for all one-third-octave bands having frequencies greater than that of LGB must be reconstructed using this method. Any time extrapolated levels should be categorized as reconstructed. Reconstruct the levels for the masked bands using the following equation:

$$L_{X_{i,k}} = L_{i,m} + \left[\frac{SR_m}{100} - \frac{SR_k}{100}\right] \times a_i + 20\log_{10}\left[\frac{SR_m}{SR_k}\right]$$

where:

$L_{X_{i,k}}$ is the time-extrapolated level in dB for band *i* and spectral record *k*;

$L_{i,m}$ is the adjusted level in dB for band *i* in spectral record *m*, which is the nearest record in time to record *k* in which band *i* contains a valid level;

SR_m is the slant range or acoustic propagation distance in meters at the time of noise emission for spectral record *m*, between the aircraft and the microphone;

SR_k is the slant range or acoustic propagation distance in meters at the time of noise emission for spectral record *k*, between the aircraft and the microphone; and

a_i is the test day atmospheric absorption coefficient (dB per 100 m) for band *i*.

This procedure is based on the assumption that the aircraft spectrum is omnidirectional during the aircraft passby.

3.3 After reconstruction of masked data has been performed, the background noise adjustment procedure is complete. The adjusted as-measured data set, comprised of adjusted levels, reconstructed levels, and possibly some masked levels, is next used to obtain the test day PNLT time-history described in FAR Part 36, Appendix A, Section A36.4. The identification of masked data should be kept accessible for use during the tone-correction procedure, since any tone correction which results from the adjustment for background noise may be eliminated from the process of identifying the maximum tone within a spectrum. When this background noise adjustment procedure is used, the band identified as LGB should be treated as the last band of the tone-correction calculation, in the manner prescribed for the 10 kHz band in FAR Part 36, Appendix A, Section A36.4.3.1, including the calculation of a new slope for band LGB+1 that equals the slope at LGB (I.e.: s'(LGB+1,*k*) = s'(LGB,*k*), in Step 5 of the tone correction procedure).

4.0 General Considerations

4.1 Limitations and requirements for **any** background noise adjustment procedure: Any method of adjusting for the effects of background noise must be approved by the certificating authority before being used. The adjustment procedure presented in Section 3.2 of this appendix includes applicable limitations and requirements. Those limitations and requirements which apply to **all** methodologies are described below:

4.1.1 The applicant must be able to demonstrate that no significant aircraft-generated tones occur in masked one-third-octave bands during the EPNL duration by means of narrow-band analysis or other methods.

4.1.2 Neither frequency-dependent adjustments nor energy-subtraction of pre-detection levels can be applied to masked data.

4.1.3 Whenever levels at or below 0 dB occur, whether as part of the original analysis or as a result of the background noise adjustment procedure, their values must be maintained and included in all relevant calculations. Such levels can become significant during the adjustment of test data to reference conditions, especially over long propagation distances, where the effects of atmospheric absorption on higher frequency data can produce large one-third-octave band adjustments.

4.1.4 When consecutive one-third-octave bands in the range of 2.5 kHz to 10 kHz inclusive are masked, and when no consecutive bands are masked in the region of 800 Hz to 2 kHz inclusive, frequency extrapolation (as described in Section 3.2.10.a) must be performed on all consecutive masked bands having nominal frequencies greater than 2 kHz.

4.1.5 When consecutive one-third-octave bands in the range of 800 Hz to 2 kHz inclusive are masked, time extrapolation (as described in Section 3.2.10.b) must be performed on all consecutive, masked bands having nominal frequencies greater than 630 Hz.

4.1.6 For cases where a single masked one-third-octave band occurs between two adjacent valid bands, the levels of the adjacent adjusted bands may be arithmetically averaged, and the averaged level used in place of the masked level. If the masked level is retained, it must be included in the count of masked levels in Section 4.2.

4.2 Rejection of spectra due to masking: the following conditions render a spectrum invalid (Note: If an invalid spectrum occurs within the 10 dB-down period, the aircraft test run is invalid, and cannot be used for aircraft noise certification purposes):

4.2.1 If, after any reconstruction of masked bands, more than four one-third-octave bands retain masked values.

4.2.2 For records within one second of the record associated with the PNLTmax spectrum (five ½-second data records), if more than four high frequency bands require reconstruction, or

if LGB is located at or below the 4 kHz one-third-octave band when the example background noise adjustment procedure presented in Section 3.2 of this appendix is used.

4.3 Special tone-correction considerations due to masking: When the maximum tone-correction for a one-third-octave band spectrum occurs at a masked or reconstructed band, the tone-correction for that spectrum cannot simply be set to zero. The maximum tone-correction for the spectrum must be computed, taking masked or reconstructed levels into consideration. Any tone correction resulting from adjustment for background noise may be eliminated by one of the following two methods as appropriate:

4.3.1 When the example background noise adjustment procedure presented in Section 3.2 of this appendix is used (or specifically, when all of the high frequency bands in a spectrum are masked for frequencies beyond a certain band, "LGB"), the band labeled as LGB should be treated as the last band of the tone-correction calculation, in the manner prescribed for the 10 kHz band in FAR Part 36, Appendix A, Section A36.4.3.1, including calculation of a new slope for the band above LGB that equals the slope of the band at LGB ($s'(LGB+1,k) = s'(LGB,k)$) in Step 5 of the tone-correction procedure.

4.3.2 For tone-corrections that occur at one-third-octave bands that are masked or reconstructed, set F equal to 0 in Step 9 of the tone-correction procedure, and recalculate the maximum tone-correction for that spectrum.

Note that all band levels within a spectrum, whether adjusted, reconstructed, or masked, must be included in the computation of the PNL value for that spectrum.

4.3 Handling of masked data in reference conditions data set: for any one-third-octave band spectrum adjusted to reference conditions, all bands, including those containing masked levels or reconstructed levels (including values less than 0 dB) must be adjusted for differences between test and reference conditions (i.e., atmospheric absorption and spherical spreading). The special tone-correction considerations listed in Section 3.2 of this appendix apply to both test and reference data sets.