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# Environmental Technical Manual on the Use of Procedures in the Noise Certification of Aircraft

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and published under his authority

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# FOREWORD

The material for this manual has been prepared by the ICAO Committee on Aviation Environmental Protection (CAEP) and approved during its sixth meeting (CAEP/6) in February 2004. The manual is periodically revised under the supervision of the CAEP Steering Group in order to make the most recent information available to certificating authorities, noise certification applicants and other interested parties in a timely manner, aiming at achieving the highest degree of harmonisation possible. These Steering Group revised versions (SGRs) will be posted on the ICAO website (http://www.icao.int/) under "publications" until the latest approved revision is submitted to future CAEP for formal endorsement and subsequent publication by ICAO.

Comments on this manual, particularly with respect to its application and usefulness, would be appreciated from all States. These comments will be taken into account in the preparation of subsequent editions. Comments concerning this manual should be addressed to:

The Secretary General
International Civil Aviation Organization
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# NOMENCLATURE

## Symbols and Units

Symbols and abbreviations employed in this manual are consistent with those contained in Annex 16 — *Environmental Protection*, Volume I — *Aircraft Noise* (Third Edition, July 1993).

| *Symbol* | *Unit* | *Description* |
|---|---|---|
| c | m/s | Speed of sound |
| CI | dB | 90 per cent confidence interval in decibel units relevant to the calculation being made. |
| D | m | Jet nozzle diameter based on total nozzle exit area. |
| dB | decibel | |
| EPNL | EPNdB | Effective Perceived Noise Level |
| $\text{EPNL}_r$ | EPNdB | Effective Perceived Noise Level at reference conditions |
| F | N | Engine net thrust |
| f | Hz | One-third octave band centre frequency |
| $H_R$ | ft | Reference height |
| ICD | — | Inflow control device |
| K | — | Constant |
| kt | knot | |
| L | dBA | A-weighted sound pressure level |
| M | — | Mach number |
| $M_H$ | — | Propeller helical tip Mach number |
| MAP | in. Hg | Manifold air pressure |
| ms | millisecond | |
| $N_P$ | rpm | Propeller rotational speed |
| $N_1$ | rpm | Low pressure rotor speed of turbine engines |
| OASPL | dB | Overall sound pressure level |
| PNL | PNdB | Perceived Noise Level |
| PNLT | TPNdB | Tone Corrected Perceived Noise Level |
| $\text{PNLT}_r$ | TPNdB | Tone Corrected Perceived Noise Level at reference conditions |
| PNLTM | TPNdB | Maximum Tone Corrected Perceived Noise Level |
| S | — | Strouhal number (fD/$V_j$) |
| SHP | kW | Shaft horsepower |
| SPL | dB | Sound pressure level based on a reference of 20 μPa |
| TCL | °C | Air temperature at engine centreline height |
| TMIC | °C | Air temperature at the near-ground-plane microphone height |
| V | m/sec | Aircraft airspeed |
| $V_{CMP}$ | | |
| $V_j$ | m/sec | Jet velocity for complete isentropic expansion to ambient pressure |
| $V_{MO}$ | | |
| $V_{nom}$ | m/sec | Nominal airspeed for noise-power-distance (NPD) plot |
| $V_r$ | m/sec | Aeroplane reference speed |
| $V_y$ | m/sec | Aircraft best rate of climb speed |
| WCL | km/h | Average wind speed at engine centreline height |
| x | m | Distance downstream from nozzle exit |
| $\delta_{amb}$ | — | Ratio of absolute static pressure of the ambient air at the height of the aeroplane to ISA air pressure at mean sea level (i.e. 101.325 kPa) |
| $\theta_{t2}$ | — | Ratio of absolute static temperature of the air at the height of the aeroplane to the absolute temperature of the air at sea level for ISA conditions (i.e. 288.15°K) |
| $\mu$ | — | Engine power related parameter or mean value (see Appendix 1) |
| $\lambda$ | degrees | Angle between the flight path in the direction of flight and a straight line connecting the aeroplane and the microphone at the time of sound emission |
| $\sigma$ | — | Ratio of atmospheric air density at altitude to that at sea level for ISA conditions |

### Suffixes

| | |
|---|---|
| flt | Quantity related to flight conditions |
| max | Maximum value |
| ref | Quantity related to reference conditions |
| static | Quantity related to static conditions |
| test | Quantity related to test conditions |
| DOP | Doppler related quantity |

### Abbreviations

| | |
|---|---|
| BPR | Bypass ratio |
| CAS | Calibrated airspeed |
| ESDU | Engineering Sciences Data Unit |
| FAA | Federal Aviation Administration (of the United States of America) |
| FAR | Federal Aviation Regulations (of the United States of America) |
| IAS | Indicated airspeed |
| ICCAIA | International Coordinating Council of Aerospace Industries Association |
| ICD | Inflow control device |
| INS | Inertial navigation system |
| IRIG-B | Inter-range Instrumentation Group of the Range Commanders Council |
| ISA | International Standard Atmosphere |
| MSL | Mean sea level |
| NAC | No acoustical change |
| NPD | Noise-power-distance |
| OAT | Outside air temperature |
| PCM | Pulse code modulation |
| RH | Relative humidity |
| SAE AIR | Society of Automotive Engineers — Aerospace Information Report |
| SAE ARP | Society of Automotive Engineers — Aerospace Recommended Practice |
| SEL | Sound exposure level |
| SFE | Static-to-flight equivalencies |
| SLR | Single-lens reflex |
| TAS | True airspeed |
| TCS | Turbulence control screen |
| VTOL | Vertical take-off and landing |
| WGAR | Working Group Approved Revision |

*Note.— Where log is used in this document, it denotes logarithm to the base of 10.*

# Chapter 1

# GENERAL

## 1.1 PURPOSE

1.1.1 The aim of this manual is to promote uniformity in the implementation of the technical procedures of Annex 16 — *Environmental Protection*, Volume I — *Aircraft Noise*, and to provide guidance so that all certificating authorities can apply the same degree of stringency and the same criteria in accepting and approving applications for the use of equivalent procedures.

1.1.2 This manual provides guidance in the wider application of equivalent procedures that have been accepted as a technical means for demonstrating compliance with the noise certification requirements of Annex 16, Volume I. Such equivalent procedures are referred to in Annex 16, Volume I, but are not dealt with in the same detail as in the Appendices to Annex 16, Volume 1 (which describe the noise evaluation methods for compliance with the relevant chapters of Annex 16, Volume 1).

1.1.3 Annex 16, Volume I procedures must be used unless an equivalent procedure is approved by the certificating authority. Equivalent procedures should not be considered as limited only to those described herein, as this manual will be expanded as new procedures are developed.

1.1.4 For the purposes of this manual, an equivalent procedure is a test or analysis procedure which, while differing from one specified in Annex 16, Volume I, in the technical judgement of the certificating authority, yields effectively the same noise levels as the specified procedure.

1.1.5 References to Annex 16, Volume I relate to the Amendment 7 thereof.

## 1.2 FRAMEWORK

Equivalent procedures fall into two broad categories: 1) those which are generally applicable and 2) those which are applicable to a particular aircraft type. For example, some equivalencies dealing with measurement equipment may be used for all types of aircraft, but a given test procedure may only be appropriate for jet aeroplanes and not for turboprop aeroplanes. Consequently this manual is structured to provide information on equivalent procedures applicable to the types of aircraft covered by Annex 16, Volume I, i.e. jet, propeller-driven heavy and light aeroplanes, and helicopters. Equivalent procedures applicable to each aircraft type are identified in separate chapters. Each chapter covers, in the main, flight test equivalencies, the use of analytical procedures and equivalencies in evaluation procedures.

## 1.3 INCORPORATION OF EQUIVALENT PROCEDURES INTO THE NOISE COMPLIANCE DEMONSTRATION PLAN

1.3.1 Prior to undertaking a noise certification demonstration, the applicant is normally required to submit to the certificating authority a noise compliance demonstration plan. This plan contains the method by which the applicant proposes to show compliance with the noise certification requirements of Annex 16, Volume I. Approval of this plan and the proposed use of any equivalent procedure remains with the certificating authority. The procedures in this manual are grouped according to specific applications. The determination of equivalency for any procedure or group of procedures must be based upon the consideration of all pertinent facts relating to the application.

1.3.2 The use of equivalent procedures may be requested by applicants for many reasons, such as:

a) to make use of previously acquired certification test data for the aeroplane type;

b) to permit and encourage more reliable demonstration of small noise level differences among derived versions of an aeroplane type; and

c) to minimize the costs of demonstrating compliance with the requirements of Annex 16, Volume I by keeping aircraft test time, airfield usage, and equipment and personnel costs to a minimum.

1.3.3 The material included in this manual is for technical guidance only. The use of past examples of approved equivalencies does not imply that these equivalencies are the only acceptable ones, neither does their presentation imply any form of limitation of their application nor does it imply commitment to further use of these equivalencies.

## 1.4 CHANGES TO THE NOISE CERTIFICATION LEVELS FOR DERIVED VERSIONS

1.4.1 Many of the equivalent procedures given in this manual relate to derived versions, where the procedure used yields the information needed to obtain the noise certification levels of the derived version by adjusting the noise levels of the "flight datum" aircraft (i.e. the most appropriate aircraft for which the noise levels were measured during an approved Annex 16, Volume I flight test demonstration).

1.4.2 The physical differences between the "flight datum" aircraft and the derived version can take many forms, such as an increased take-off weight, an increased engine thrust, changes to the powerplant or propeller or rotor types, etc. Some of these differences will alter the distance between the aircraft and the noise certification reference points, others the noise source characteristics. Procedures used in the determination of the noise certification levels of the derived versions will therefore depend upon the change to the aircraft being considered. However, where several similar changes are being made, such as the introduction of engines from different manufacturers, the procedures used to obtain the noise certification levels of each derivative aircraft should be followed in identical fashion.

1.4.3 Aircraft/engine model design changes and airframe/engine performance changes may result in very small changes in aircraft noise certification levels that are not acoustically significant. These changes are referred to as no-acoustical changes (NACs). For this manual, NACs, which do not result in modification of an aircraft's noise certification levels, are defined as:

a) changes in aeroplane noise certification levels approved by the certificating authority which do not exceed 0.1 dB at any noise measurement point and which an applicant does not track;

b) cumulative changes in aeroplane noise certification levels approved by the certificating authority whose sum is greater than 0.1 dB but not more than 0.3 dB at any noise measurement point and for which an applicant has an approved tracking procedure; and

c) changes in helicopter noise certification levels approved by the certificating authority which do not exceed 0.3 dB at any one of the noise certification levels.

1.4.4 With respect to the tracking procedure referred to in 1.4.3 b), noise certification approval has been given based upon the following criteria:

a) ownership by the certification applicant of the noise certification database and tracking process based on an aircraft/engine model basis;

b) when the 0.3 dB cumulative change in aeroplane noise certification level is exceeded, compliance with Annex 16 Volume I requirements is required. The aircraft certification noise levels may not be based upon summation of NAC noise increments;

c) decreases in noise level should not be included in the tracking process unless the type design change will be retrofitted to all aircraft in service and included on newly produced aircraft;

d) aircraft/engine design changes resulting in noise level increases should be included in the tracking process regardless of the extent of retrofit to aircraft in service;

e) tracking of an aircraft/engine model should, in addition to engine design changes, include airframe, and performance changes;

f) tracked noise increments should be determined on the basis of the most noise sensitive condition and be applied to all configurations of the aircraft/engine model;

g) the tracking should be revised to account for a tracked design change increment that is no longer applicable;

h) changes should be tracked to two decimal places (e.g. 0.01 dB). Round-off shall not be considered when judging an NAC (e.g. 0.29 dB = NAC; 0.30 dB = NAC; 0.31 dB = acoustical change);

i) an applicant should maintain formal documentation of all NACs approved under a tracking process for an airframe/engine model. The tracking list will be reproduced in each noise certification dossier demonstration; and

j) due to applicability dates for Chapters of Annex 16, Volume I, concerning helicopters and light-propeller driven aeroplanes, some aircraft are not required to have certified noise levels. However some modifications to these aircraft can be applied which may impact the noise characteristics. In this case, the no-acoustical criterion application will be treated with a procedure approved by the certificating authority.

1.4.5 Noise certification approval of modified helicopters should be granted according to the following criteria:

a) an NAC approval for a derived version shall be made only if the certificated noise levels were acquired by testing the "flight datum" helicopter design;

b) noise levels for a helicopter designated as an NAC design cannot be used as the "flight datum" for any subsequent design changes; and

c) for changes exceeding 0.3 dB, compliance with Annex 16 Volume I requirements can be achieved either by testing or, subject to the approval of the certificating authority, by analytical means. If analytical means are employed, the noise certification levels cannot be used as the "flight datum" for any subsequent design changes.

A flow chart illustrating the criteria for dealing with modified helicopters is presented in Figure 1-1.

## 1.5 RE-CERTIFICATION

1.5.1 Re-certification is defined as the "certification of an aircraft, with or without revision to noise levels, to a Standard different to that which it had been originally certified".

1.5.2 In the case of an aircraft being re-certificated from the Standards of Annex 16, Volume I, Chapters 3 or 5 to Chapter 4 noise re-certification should be granted on the basis that the evidence used to determine compliance is as satisfactory as the evidence associated with a new type design. The date used by a certificating authority to determine the re-certification basis should be the date of acceptance of the first application for re-certification.

1.5.3 The basis upon which the evidence associated with applications for re-certification (as described in 1.5.2) should be assessed is presented in Appendix 8 of this manual.

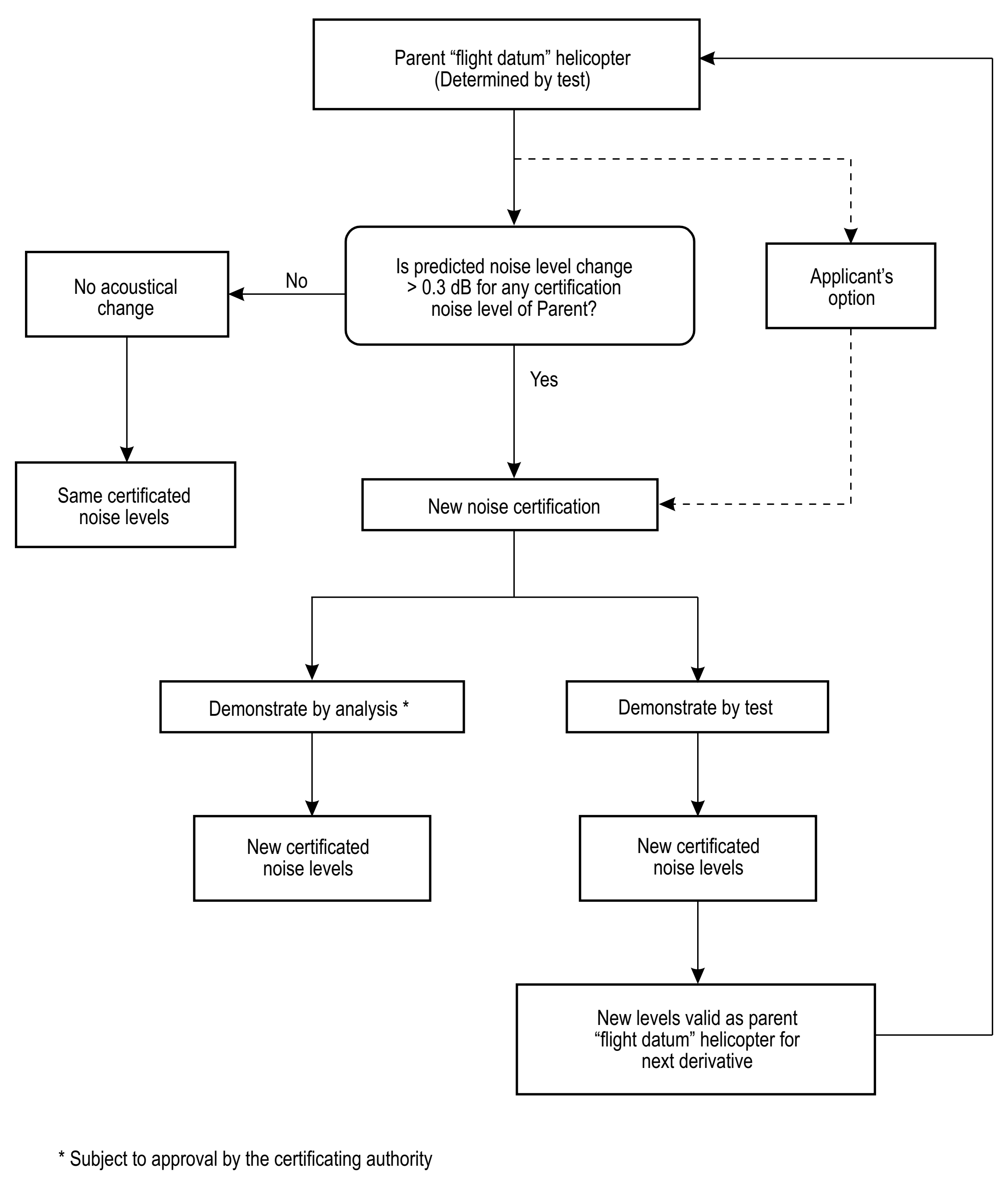


**Figure 1-1. "No acoustical change" criteria for helicopters**

# Chapter 2

# EQUIVALENT PROCEDURES FOR SUBSONIC JET AEROPLANES

The objective of a noise demonstration test is to acquire data for establishing an accurate and reliable definition of the aeroplane's noise characteristics under reference conditions [see 2.6 of Annex 16 — *Environmental Protection*, Volume I — *Aircraft Noise*, specifically 2.6 (for Chapter 2 aeroplanes), 3.6 (for Chapter 3 aeroplanes) and 4.5 (for Chapter 4 aeroplanes)]. In addition, Annex 16 sets forth a range of test conditions and the procedures for adjusting measured data to reference conditions.

## 2.1 FLIGHT TEST PROCEDURES

The following methods have been used to provide equivalent results to procedures described in Chapters 2 and 3 of Annex 16, Volume I for jet aeroplanes. They are also considered to provide equivalent results to the procedures defined for Chapter 4 aeroplanes.

### 2.1.1 Flight path intercept procedures

2.1.1.1 Flight path intercept procedures, in lieu of full take-off and/or landing profiles described in 9.2 and 9.3 of Appendix 1 or in 9.2 of Appendix 2 of Annex 16, Volume I, have been used to meet the demonstration requirements for noise certification. The intercept procedures have also been used in the implementation of the generalized flight test procedures described in 2.1.2 of this manual. The use of intercepts eliminates the need for actual take-offs and landings (with significant cost and operational advantages at high gross mass) and substantially reduces the test time required. Site selection problems are reduced and the shorter test period provides a higher probability of stable meteorological conditions during testing. Aeroplane wear and fuel consumption are reduced, while greater consistency and quality in noise data are obtained.

2.1.1.2 Figure 2-1 a) illustrates a typical take-off profile. The aeroplane is initially stabilized in level flight at a point *A* and continues to point *B* where take-off power is selected and a steady climb is initiated. The steady climb condition is achieved at point *C*, intercepting the reference take-off flight path and continuing to the end of the noise certification take-off flight path. Point *D* is the theoretical take-off rotation point used in establishing the reference flight path. If thrust (power) reduction is employed, point *E* is the point of application of thrust (power) reduction and point *F*, the end of the noise certification take-off flight path. The distance *TN* is the distance over which the position of the aeroplane is measured and synchronized with the noise measurement at point *K*.

2.1.1.3 For approach, the aeroplane usually follows the planned flight trajectory while maintaining a constant configuration and power until there is no influence on the noise levels within 10 dB of the Maximum Tone Corrected Perceived Noise Level (PNLTM). The aeroplane then carries out a go-around rather than continuing the landing (see Figure 2-1 b)).

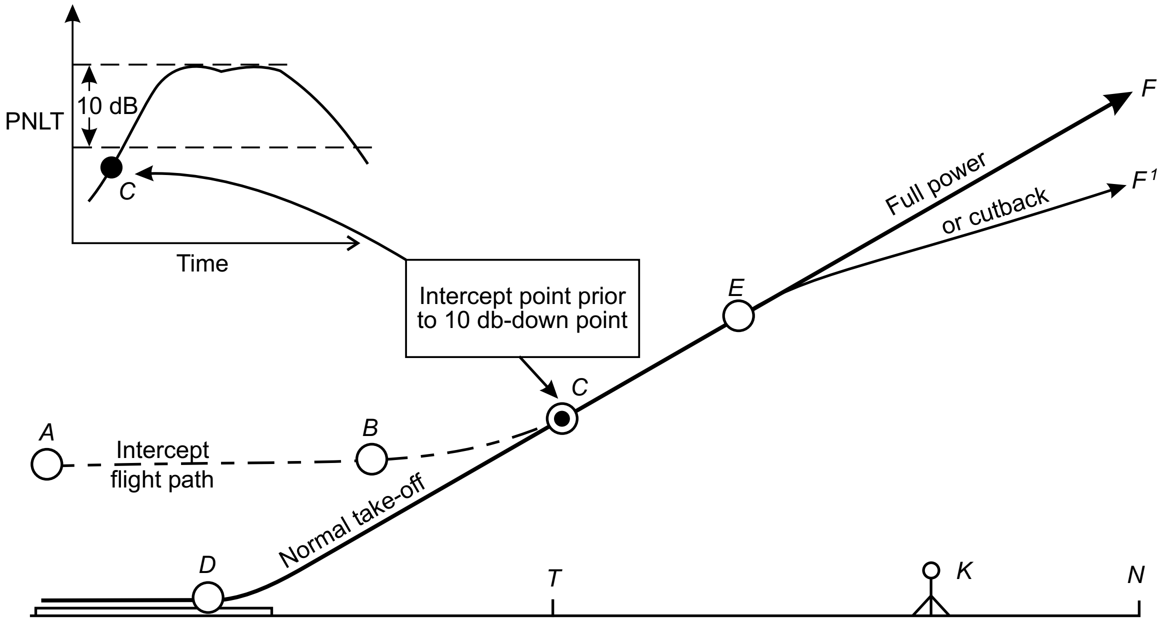
2.1.1.4 For the development of the noise-power-distance (NPD) data for the approach case (see 2.1.2.1), the speed and approach angle constraints imposed by Annex 16, Volume I in 2.6.2, 3.6.3, 3.7.5, 4.5 and 4.6 cannot be satisfied over the typical ranges of thrust needed. For the approach case, a steady speed of $V_{REF}$ + *19 km/h* ($V_{REF}$ + *10 kt*) should be maintained to within ±9 km/h or ±5 kt and the flyover height over the microphone should be 400 ft ±100 ft. Within these constraints the test approach angle at the test thrust should be that resulting from the test aircraft conditions (i.e. mass, configuration, speed and thrust).

2.1.1.5 The flight profiles should be consistent with the test requirements of Annex 16 over a distance that corresponds at least to noise levels that are 10 dB below the PNLTM obtained at the measurement points during the demonstration.

### 2.1.2 Generalized flight test procedures

The following equivalent flight test procedures have been used for noise certification compliance demonstrations.

2-1a Take-off intercept



2-1b Approach (Break-off)

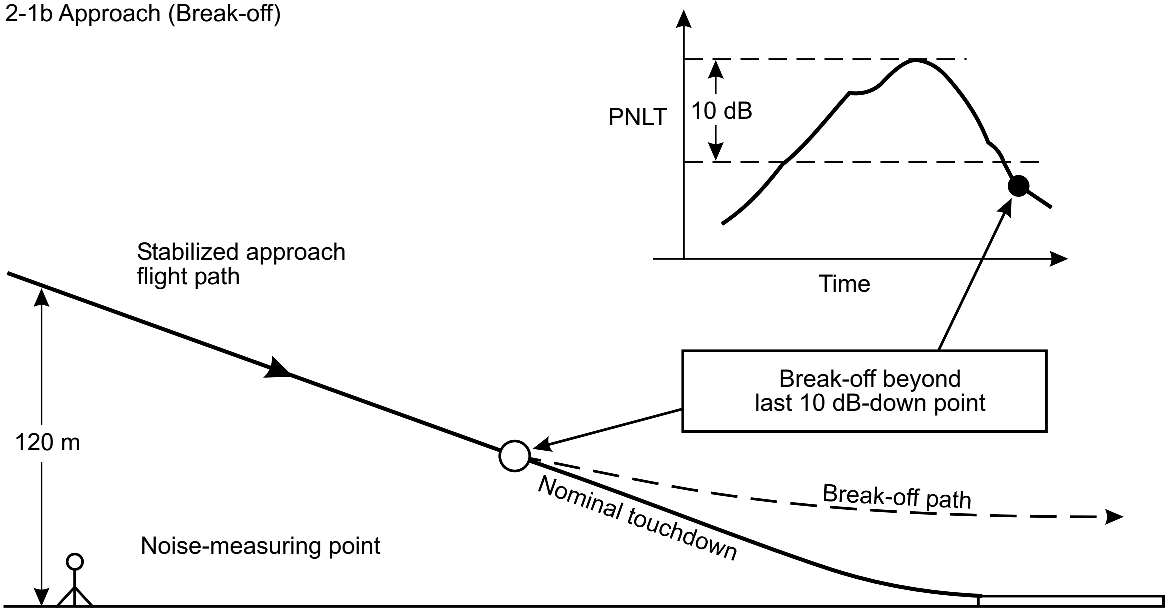


**Figure 2-1. Flight path intercept procedures**

2.1.2.1 *Derivation of noise-power-distance (NPD) data*

2.1.2.1.1 For a range of thrusts (powers) covering full take-off and reduced thrusts (powers), the aeroplane is flown past lateral and under-flight-path microphones according to either the take-off procedures defined in 3.6.2 and 4.5 of Annex 16, Volume I or, more typically, the flight path intercept procedures described in 2.1.1 of this manual. Target test conditions are established for each sound measurement. These target test conditions define the flight procedure, aerodynamic configuration to be selected, aeroplane weight, power, airspeed and, at the closest point of approach to the measurement location, height. Regarding choice of target airspeeds and variation in test weights, the possible combinations of these test elements may affect the aeroplane angle-of-attack or aeroplane attitude and therefore possibly the aeroplane sound generation or propagation geometry. The aeroplane angle-of-attack will remain approximately constant for all test weights if the tests are conducted at the take-off reference airspeed appropriate for each test weight. (For example, if the appropriate take-off reference airspeed for the aeroplane is $V_2+15\ kt$, then set the target airspeed for each test weight at $V_2+15\ kt$; the actual airspeed magnitude will vary according to each test weight but the aeroplane test angle-of-attack will remain approximately constant.) Alternatively, for many aeroplanes the aeroplane attitude remains approximately constant for all test weights if all tests are conducted at the magnitude of the take-off reference airspeed corresponding to the maximum take-off weight. (For example, if the approximate take-off reference airspeed for the aeroplane is $V_2+15\ kt$, then set the target airspeed for each test weight at the magnitude of the $V_2+15\ kt$ airspeed that corresponds to the maximum take-off weight; the airspeed magnitude remains constant for each test weight and the aeroplane attitude remains approximately constant.) Review of these potential aeroplane sensitivities may dictate the choice of target airspeeds and/or test weights in the test plan in order to limit excessive changes in angle-of-attack or aeroplane attitude that could significantly change measured noise data. In the execution of each condition, the pilot should "set up" the aeroplane in the appropriate condition in order to pass by the noise measurement location within the target height window, while maintaining target power and airspeed, within agreed tolerances, throughout the 10dB-down time period.

2.1.2.1.2 A sufficient number of noise measurements are made in order to establish noise-power curves at a given distance for both lateral and flyover cases These curves are extended either by calculation or by the use of additional flight test data to cover a range of distances, to form the generalized noise database for use in the noise certification of the "flight datum" and derived versions of the aeroplane type and are often referred to as noise-power-distance (NPD) plots (see Figure 2-2). If over any portion of the range for the NPD plot, the criteria for calculating the Effective Perceived Noise Level (EPNL) given in 9.1.2 of Appendix 2 of Annex 16, Volume I requires the use of the integrated procedure, then this procedure shall be used for the whole NPD plot. The 90 per cent confidence intervals about the mean lines are constructed through the data (see 2.2 of Appendix 1 of this manual).

*Note.— The same techniques can be used to develop NPD plots that are appropriate for deriving approach noise levels by flying over an under-flight-path microphone for a range of approach powers, using the speed and aeroplane configuration given in 3.6.3 and 4.5 of Annex 16, Volume I, or more typically, the flight test procedures described in 2.1.1 of this manual.*

2.1.2.1.3 The availability of flight test data for use in data adjustment (e.g. speed and height) should be considered in test planning as such availability may limit the extent to which a derived version may be certificated without further flight testing, especially where the effects of airspeed on source noise levels become significant. The effects of high altitude test site location on jet noise source levels should also be considered in test planning. High altitude test site locations have been approved under conditions specified in Appendix 6 of this manual, provided that jet noise source corrections are applied to the noise data. The correction method described in Appendix 6 has been approved for this purpose.

2.1.2.1.4 The flyover, lateral and approach noise measurements should be corrected to the reference speed and atmospheric conditions over a range of distances in accordance with the procedures described in Appendix 1 (for Chapter 2 aeroplanes) or Appendix 2 (for Chapter 3 and Chapter 4 aeroplanes) of Annex 16, Volume I. The NPD plots can then be constructed from the adjusted EPNL, power and distance plots. These plots present the EPNL values for a range of distance and engine noise performance parameters (see Annex 16, Volume I, Appendix 2, 9.3.4.1). The parameters are usually the corrected low pressure rotor speed $N_1/\sqrt{\theta_{t2}}$ or the corrected net thrust $F_N/\delta_{\text{amb}}$ (see Figure 2-2), where:

$N_1$ is the actual low pressure rotor speed;

$\theta_{t2}$ is the ratio of absolute static temperature of the air at the height of the aeroplane to the absolute temperature of the air for an International Standard Atmosphere (ISA) at mean sea level (i.e. 288.15 K);

$F_N$ is the actual engine net thrust per engine; and

$\delta_{amb}$ is the ratio of absolute static pressure of the ambient air at the height of the aeroplane to ISA air pressure at mean sea level (i.e. 101.325 kPa).

2.1.2.1.5 Generalized NPD data may be used in the certification of the flight tested aeroplane and derivative versions of the aeroplane type. For derived versions, these data may be used in conjunction with analytical procedures, static testing of the engine and nacelle, or additional limited flight tests to demonstrate compliance.

2.1.2.2 *Flight test procedures for the determination of changes in aeroplane certificated noise levels*

Noise level changes determined by comparison of flight test data for different configurations of an aeroplane type have been used to establish certification noise levels of newly derived versions by reference to the noise levels of the "flight datum" aeroplane. These noise level changes are added to or subtracted from the noise levels obtained from individual flights of the "flight datum" aeroplane. Confidence intervals of new data are statistically combined with the "flight datum" data to develop overall confidence intervals (see Appendix 1 of this manual).

### 2.1.3 Determination of the lateral noise certification levels

2.1.3.1 Alternative procedures using two microphone stations located symmetrically on either side of the take-off reference track have proven to be effective in terms of time and costs savings. Such an arrangement avoids many of the difficulties encountered when using the more conventional multi-microphone arrays. The procedures consist of flying the test aeroplane at full take-off thrust (power) at one or more specified heights above a track at right angles to and

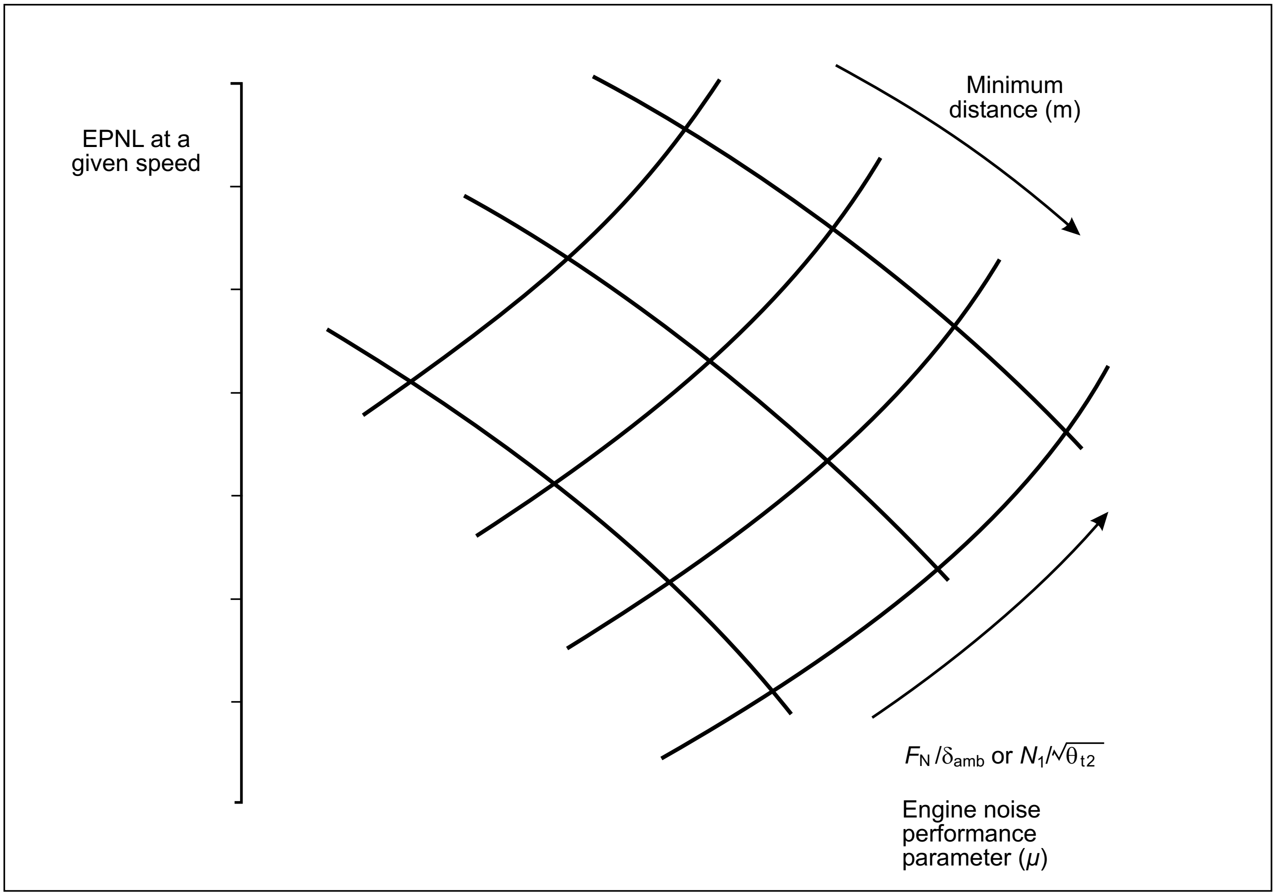


Figure 2-2. Form of noise-power-distance (NPD) plot for turbojet or turbofan powered aeroplanes

midway along the line joining the two microphone stations. However, when this procedure is used, matching data from both lateral microphones for each fly-by should be used for the lateral noise determination; cases where data from only one microphone is available for a given run must be omitted from the determination. The following paragraphs describe the procedures for determining the lateral noise level for subsonic turbojet or turbofan powered aeroplanes.

2.1.3.2 Lateral noise measurements for a range of conventionally configured aeroplanes with under wing and/or rear-fuselage mounted engines with bypass ratio of more than 2 have shown that the maximum lateral noise at full power normally occurs when the aeroplane is close to 300 m (985 ft) or 435 m[1] (1 427 ft) in height during the take-off. Based on this finding it is considered acceptable to use the following as an equivalent procedure:

a) for aeroplanes to be certificated under Chapters 2, 3 and 4 of Annex 16, Volume I, two microphone locations are used, symmetrically placed on either side of the aeroplane reference flight track and 450 m or 650 m[1] from the reference flight track;

b) for aeroplanes with engines with bypass ratio of more than 2, the height of the aeroplane as it passes the microphone stations should be 300 m (985 ft) or 435 m[1] (1 427 ft) and be no more than +100 m, 50 m (+328 ft, –164 ft) relative to this target height. For aeroplanes with bypass ratio of 2 or less, it is necessary to determine the peak lateral noise by undertaking a number of flights over a range of heights to define the noise (EPNL) versus height characteristics. A typical height range would cover 60 m (200 ft) to 600 m (2 000 ft) above the intersection of a track at right angles to the line joining the two microphone positions and this line;

c) constant power, configuration and airspeed as described in 2.6.1.2 and 2.6.1.3 of Chapter 2, 3.6.2.1a) and 3.6.2.1d) of Chapter 3 and 4.5 of Chapter 4 of Annex 16, Volume I should be used during the flight demonstration;

d) adjustment of measured noise levels should be made to the acoustical reference day conditions and to reference aeroplane operating conditions as specified in Section 9 of Appendices 1 and 2 of Annex 16, Volume I; and

e) to account for any possible asymmetry effects in measured noise levels, the reported lateral Effective Perceived Noise Level at reference condition ($EPNL_r$) values needed for purposes of demonstrating compliance with the applicable noise limit of Chapters 3 and 4 or Chapter 2 of Annex 16, Volume I, as applicable, should be the arithmetic average of the $EPNL_r$ values from each of the two lateral measurement points. Compliance should be determined within the ±1.5 dB 90 per cent confidence interval required by Annex 16 (see Section 2 of Appendix 1 of this manual).

2.1.3.3 Certificated lateral noise levels have also been determined by using multiple pairs of lateral microphones rather than only one pair of symmetrically located microphones. A sufficient number of acceptable data points, resulting from a minimum of six runs, must be obtained from sufficiently spaced microphone pairs in order to adequately define the maximum lateral $EPNL_r$ value and provide an acceptable 90 per cent confidence interval.

### 2.1.4 Take-off flyover noise levels with thrust (power) reduction

Flyover noise levels with thrust (power) reduction may also be established without making measurements during take-off with full thrust (power) followed by thrust (power) reduction in accordance with 2.2.1 of this manual.

### 2.1.5 Measurements at non-reference points

2.1.5.1 In some instances test measurement points may differ from the reference measurement points specified in 2.3.1, 3.3.1 and 4.3 of Chapters 2, 3 and 4, respectively, in Annex 16, Volume I. Under these circumstances an applicant may request approval of data that have been adjusted from the actual measurements in order to represent data that would have been measured at the reference noise measurement points in reference conditions.

2.1.5.2 Reasons for requesting approval of such adjusted data may be:

a) to allow the use of a measurement location that is closer to the aeroplane flight path so as to improve data quality by obtaining a greater ratio of signal to background noise. Whereas Appendix 3 of this manual describes a procedure for removing the

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[1] Use with Chapter 2 procedures in Annex 16, Volume I.

effects of background noise, the use of data collected closer to the aeroplane avoids the interpolations and extrapolations inherent in the method;

b) to enable the use of an existing, approved noise certification database for an aeroplane type design in the certification of a derivative of that type, when the derivative is to be certificated under reference conditions that differ from the original type certification reference conditions; and

c) to avoid obstructions near the noise measurement point(s) which could influence sound measurements. When a flight path intercept technique is being used, flyover and approach noise measurement points may be relocated as necessary to avoid undesirable obstructions. Lateral noise measurement points may be relocated by distances which are of the same order of magnitude as the aeroplane lateral deviations (or offsets) relative to the nominal flight paths that occur during flight testing.

2.1.5.3 Approval has been granted to applicants for the use of data from non-reference noise measurement points provided that measured data are adjusted to reference conditions in accordance with the requirements of Section 9 of Appendix 1 or 2 of Annex 16, Volume I, and the magnitudes of the adjustments do not exceed the limitations cited in 3.7.6 of Chapter 3 and 4.6 of Chapter 4 and 5.4 of Appendix 1 of Annex 16, Volume I, as appropriate.

### 2.1.6 Atmospheric test conditions

Certificating authorities have found it acceptable to exceed the sound attenuation limits of Annex 16, Volume I, Appendix 2, 2.2.2c) in cases:

a) when the dew point and dry bulb temperature are measured with a device which is accurate to ± 0.5°C and are used to obtain relative humidity, and when "layered" sections of the atmosphere are used to compute equivalent weighted sound attenuations in each one-third octave band, sufficient sections being used to the satisfaction of the certificating authority; or

b) where the peak noy values at the time of Tone Corrected Perceived Noise Level (PNLT), after adjustment to reference conditions, occur at frequencies of less than or equal to 400 Hz.

## 2.2 ANALYTICAL PROCEDURES

Analytical equivalent procedures rely upon available noise and performance data obtained from flight test for the aeroplane type. Generalized relationships between noise, power and distance (for derivation of NPD plots, see 2.1.2.1) and adjustment procedures for speed changes in accordance with the methods of Appendix 1 or Appendix 2 of Annex 16, Volume I are combined with certificated aeroplane aerodynamic performance data to determine noise level changes resulting from type design changes. These noise level increments are then applied to noise levels in accordance with 2.1.2.2 of this manual.

### 2.2.1 Flyover noise levels with thrust (power) reduction

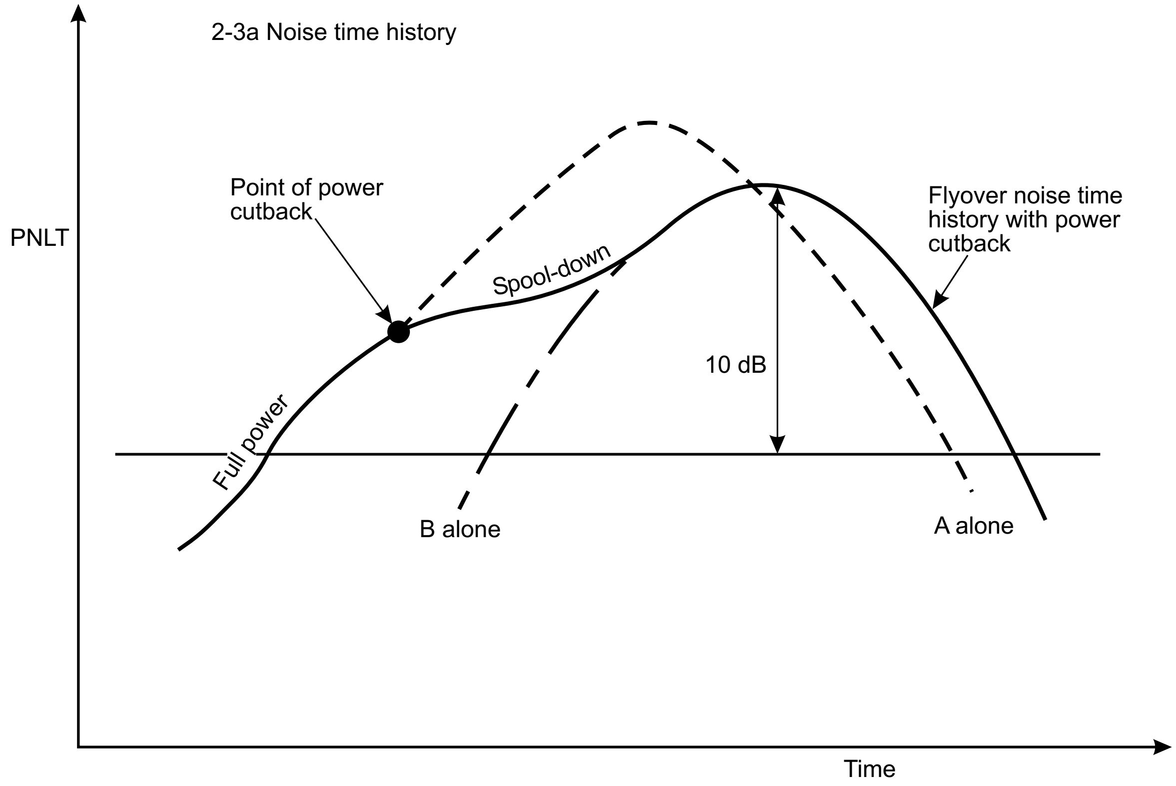
*Note.— The selection of the height of an aeroplane within the reference flight path for initiation of thrust (power) reduction should take into account both the "average engine" spool — down time and a1.0 second delay for flight crew recognition and response prior to movement of the throttles to the reduced thrust (power) position.*

2.2.1.1 Flyover noise levels with thrust (power) reduction may be established from the merging of PNLT versus time measurements obtained during constant power operations. As illustrated in Figure 2-3 a), the 10 dB-down PNLT noise time history recorded at the flyover point may contain portions of both full thrust (power) and reduced thrust (power) noise time histories. As long as these noise time histories, the average engine spool-down thrust (power) characteristics, and the aeroplane flight path during this period (see Figure 2-3 b)), which includes the transition from full to reduced thrust (power), are known, the flyover noise level may be computed.

2.2.1.2 Where the full thrust (power) portion of the noise time history does not intrude upon the 10 dB-down time history of the reduced thrust (power), the flyover noise levels may be computed from a knowledge of the NPD characteristics and the effect of the average spool-down thrust (power) characteristics on the aeroplane flight path.

*Note.— To ensure that the full thrust (power) portion of the noise time history does not intrude upon the 10 dB— down noise levels,*

$$\underset{\text{After cutback}}{PNLTM} \; - \; \underset{\text{Before cutback}}{PNLT} \; \geq 10.5 \; dB.$$


2-3a Noise time history

2-3b Flight path over flyover measuring point with power cutback

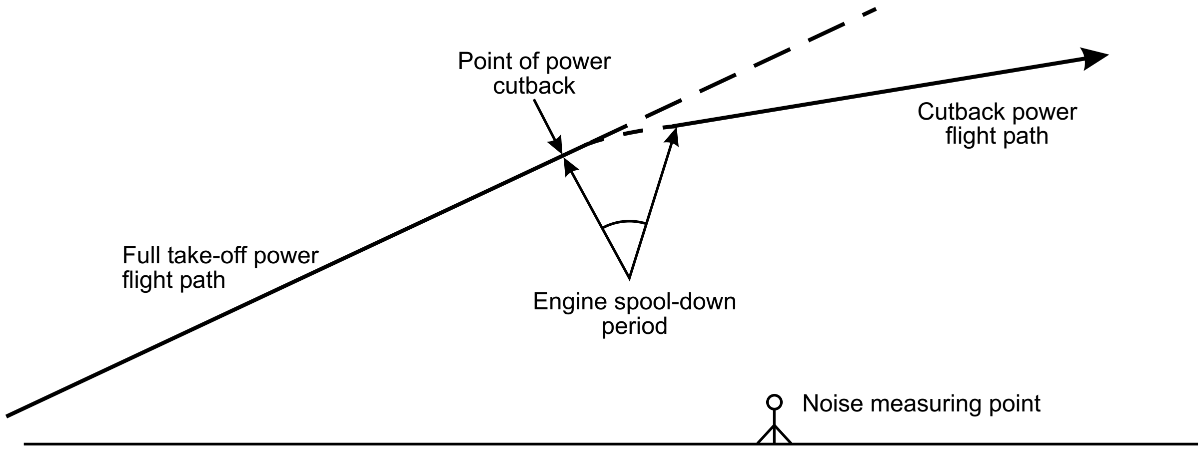


**Figure 2-3. Computation of cutback take-off noise level from constant power tests**

### 2.2.2 Equivalent procedures based on analytical methods

Noise certification approval has been given for applications based on type design changes that result in predictable noise level differences, including the following:

a) changes to the originally certificated take-off or landing mass which in turn lead to changes in distance between the aeroplane and the microphone for the take-off case and changes to the approach power. In this case the NPD data may be used to determine the noise certification level of the derived version; and

b) noise changes due to engine power changes. However, care should be taken to ensure that when NPD plots are extrapolated, the relative contribution of the component noise sources to the EPNL remains essentially unchanged and a simple extrapolation of the noise/power and noise/distance curves can be made. Among the items which should be considered in extending the NPD are:

   — the 90 per cent confidence interval at the extended thrust (power);

   — aeroplane/engine source noise characteristics and behaviour;

   — engine cycle changes; and

   — quality of data to be extrapolated;

c) aeroplane engine and nacelle configuration and acoustical treatment changes, usually leading to changes in the values of $EPNL_r$ of less than 1 dB. It should however be ensured that new noise sources are not introduced by modifications made to the aeroplane, engine or nacelles. A validated analytical noise model approved by the certificating authority may be used to derive predictions of noise increments. The analysis may consist of modelling each aeroplane component noise source and projecting the sources to flight conditions in a manner similar to the static test procedure described in 2.3. A model of detailed spectral and directivity characteristics for each aeroplane noise component may be developed by theoretical and/or empirical analysis. Each component should be correlated to the parameter(s) which relates to the physical behaviour of source mechanisms. The source mechanisms, and subsequently the correlating parameters, should be identified through use of other supplemental tests such as engine or component tests. As described in 2.3, an $EPNL_r$ value representative of flight conditions should be computed by adjusting aeroplane component noise sources for forward speed effects and for the number of engines and shielding, reconstructing the total noise spectra, and projecting the total noise spectra to flight conditions by accounting for propagation effects. The effect of changes in acoustic treatment, such as nacelle lining, may be modelled and applied to the appropriate component noise sources. The computation of the total noise increments, the development of the changed version NPD, and the evaluation of the changed version $EPNL_r$ values should be made by using the procedures described in 2.3.4.12 and 2.3.4.13 of this manual. Guidance material on confidence interval computations is provided in Appendix 1 of this manual; and

d) airframe design changes (e.g. changes in fuselage length, flap configuration and engine installation) that could indirectly affect noise levels because of an effect on aeroplane performance (e.g. increased drag). Changes in aeroplane performance characteristics derived from aerodynamic analysis or testing have been used to demonstrate how these changes affect the aeroplane flight path and hence the demonstrated noise levels of the aeroplane.

In these cases care should be exercised to ensure that the airframe design changes do not introduce significant new noise sources nor modify existing source generation or radiation characteristics. In such instances the magnitude of such effects may have to be established by test.

## 2.3 STATIC ENGINE NOISE TESTS AND PROJECTIONS TO FLIGHT NOISE LEVELS

### 2.3.1 General

2.3.1.1 Static engine noise test data provide valuable definitive information for deriving the noise levels that result from changes to an aeroplane powerplant or from the installation of a broadly similar powerplant into the airframe following initial noise certification of the “flight datum” aeroplane. This involves the testing of both the “flight datum” and derivative powerplants using an open-air test facility where the effect on the noise spectra of the engine modifications in the aeroplane may be assessed. It can also extend to the use of component test data to demonstrate that the noise levels remain unchanged where minor development changes have been made.

2.3.1.2 Approval of equivalent procedures for the use of static engine noise test data depends critically upon the availability of an adequate approved database (NPD plot) acquired from the flight testing of the "flight datum" aeroplane.

2.3.1.3 Static engine noise tests can provide sufficient additional data or noise source characteristics to allow for predictions about the effect of changes on the noise levels from the aeroplane in flight.

2.3.1.4 Types of static test accepted for the purposes of certification compliance demonstration in aeroplane development include engine and component noise tests and performance testing. Such tests are useful for assessing the effects of mechanical and thermodynamic cycle changes to the engine on the individual noise sources.

2.3.1.5 Static engine noise testing is discussed in detail in subsequent sections. For component tests, the criteria for acceptability are less definable. There are many instances, particularly when only small changes in $EPNL_r$ are expected, where component testing will provide an adequate demonstration of noise impact. For example:

a) changes in the specification of sound-absorbing linings within an engine nacelle;

b) changes in the mechanical or aerodynamic design of the fan, compressor or turbine;

c) changes to combustor designs; and

d) minor exhaust system changes.

2.3.1.6 Each proposal by an applicant to use component test data should be considered by the certificating authority with respect to the significance of the relevant affected source on the values of $EPNL_r$ for the aeroplane that is being certificated.

### 2.3.2 Limitation on the projection of static to flight data

2.3.2.1 Guidance on the acceptability, use and applicability of static engine test data are contained in subsequent sections.

2.3.2.2 The amount by which the measured noise levels of a derivative engine will differ from those of the reference engine is a function of several factors, including:

a) thermodynamic changes to the engine cycle, including increases in thrust;

b) design changes to major components (e.g. the fan, compressor, turbine, exhaust system, etc.); and

c) changes to the nacelle.

2.3.2.3 Additionally, day-to-day and test site to test site variables can influence measured noise levels and therefore the test, measurement and analysis procedures described in this manual are designed to account for these effects. In order that the degree of change resulting from aspects such as a), b) and c) in 2.3.2.2, when extrapolated to flight conditions, is restricted to acceptable amounts before a new flight test is required, a limit is needed that can be used uniformly by certificating authorities.

2.3.2.4 The recommended guideline for this limit is that the summation of the magnitudes, neglecting signs, of the noise changes for the three reference certification conditions between the "flight datum" aeroplane and the derived version at the same thrust (power) and distance (for the derived version) is no greater than 5 EPNdB, with a maximum of 3 EPNdB at any one of the reference conditions (see Figure 2-4). For differences greater than this, additional flight testing at conditions where noise levels are expected to change is recommended in order to establish a new flight NPD database.

2.3.2.5 Provided that the detailed prediction procedures used are verified by flight test for all the types of noise sources (i.e. tones, non-jet broadband and jet noise relevant to the aeroplane under consideration) and that there are no significant changes in installation effects between the aeroplane used for the verification of the prediction procedures and the aeroplane under consideration, the procedure may be employed without the limitations described in 2.3.2.4.

2.3.2.6 In addition to the limitations described in 2.3.2.4, a measure of acceptability regarding methodologies for static-to-flight projection is also needed for uniform application by certificating authorities. This measure can be derived as the residual NPD differences between the flight test data and the projected static-to-flight data for the original aeroplane version. The guideline for a measure of acceptability is to limit these residual differences to 3 EPNdB at any one of the reference conditions.

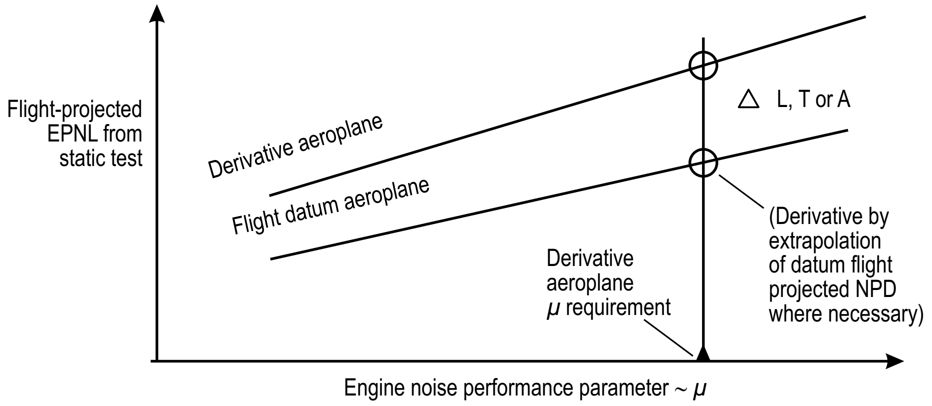
2.3.2.7 In determining the noise levels of the modified or derived version, the same analytical procedures used in the first static-to-flight calculations for the noise certification of the aeroplane type shall be used.

### 2.3.3 Static engine noise tests

2.3.3.1 *General*

2.3.3.1.1 This section provides guidelines on static engine test data acquisition, analysis and normalization techniques. The information provided is used in conjunction with technical considerations and the general guidelines for test site, measurement and analysis instrumentation, and test procedures provided in the latest version of the Society of Automotive Engineers (SAE) Aerospace Recommended Practice (ARP) 1846, namely "*Measurement of Noise from Gas Turbine Engines During Static Operation*".

2.3.3.1.2 Noise data acquired from static tests of engines with similar designs to those that were flight tested may be projected, when appropriate, to flight conditions. Once approved, said noise data may be used to supplement an approved NPD plot for the purpose of demonstrating compliance with the Annex 16, Volume I provisions in support of a change in type design. The engine designs as well as the test and analysis techniques to be used should be presented in the test plan and submitted, for approval, to the certificating authority for concurrence prior to testing.



*Definitions*

$\triangle_L$ = Difference between flight datum and derivative aeroplane EPLN at the power requirement of the derivative aeroplane at the lateral condition.

$\triangle_T$ = Difference between flight datum and derivative aeroplane EPLN at the power requirement and altitude of the derivative aeroplane at the take-off condition.

$\triangle_A$ = Difference between flight datum and derivative aeroplane EPLN at the power requirement of the derivative aeroplane at the approach condition.

*Limitations*

(i) $|\triangle_L| + |\triangle_T| + |\triangle_A|$ shall not exceed 5 EPNdB.

(ii) $\triangle_L$, $\triangle_T$ or $\triangle_A$ shall not exceed ± 3 EPNdB individually.

**Figure 2-4. Limitation on use of static test when no validating flight test data exist**

2.3.3.1.3 Test restrictions defined for flight testing in conformity with Annex 16, Volume I are not necessarily appropriate for static testing. (SAE ARP 1846 provides guidance on this subject). For example, the measurement distances associated with static tests are substantially less than those encountered in flight testing and may permit testing in atmospheric conditions not otherwise permitted for flight testing by Annex 16, Volume I. Moreover, since static engine noise is a steady sound pressure level rather than the transient noise level of a flyover, the measurement and analysis techniques may be somewhat different for static noise testing.

### 2.3.3.2 *Test site requirements*

The test site should meet at least the criteria specified in SAE ARP 1846. Different test sites may be selected for testing different engine configurations, provided the acoustic measurements from the different sites can be adjusted to a common reference condition.

### 2.3.3.3 *Engine inlet bellmouth*

The installation of a bellmouth forward of the engine inlet may be used with jet engines during static engine noise tests. Such an installation is used to provide a simulated flight condition of inlet flow during static testing. Production inlet acoustic lining and spinners are also to be installed during noise testing.

### 2.3.3.4 *Inflow control devices (ICD)*

2.3.3.4.1 Static engine noise test noise data for the noise certification of an aeroplane with a change of engine to another one of a similar design should be acquired by using an approved Inflow Control Device (ICD) for high bypass engines (BPR > 2.0). The ICD should meet the following requirements:

a) the specific ICD hardware must be inspected by the certificating authority to ensure that the ICD is free from damage and contaminants that may affect its acoustic performance;

b) the ICD must be acoustically calibrated by an approved method (such as that provided in 2.3.3.4.3) to determine its effect on sound transmission in each one-third octave band;

c) data obtained during static engine noise testing must be adjusted to account for sound transmission effects that are caused by the ICD. The adjustments shall be applied to each one-third octave band of data measured;

d) the ICD position relative to the engine inlet lip must be determined and the calibration must be applicable to that position; and

e) no more than one calibration is required for an ICD hardware design, provided that there is no deviation from the design for any one ICD serial number hardware set.

2.3.3.4.2 It is not necessary to apply the ICD calibration adjustments if the same ICD hardware (identical serial number) that was previously used in the static engine noise test of the flight engine configuration is used, and the fan tones for both engines remain in the same one-third octave bands.

### 2.3.3.4.3 ICD calibration

An acceptable ICD calibration method is as follows:

a) place an acoustic driver(s) on a simulated engine centreline in the plane of the engine inlet lip. Locate the calibration microphones on the forward quadrant azimuth at a radius between 15 m (or 50 ft) and 45 m (or 150 ft) that provides a good signal-to-ambient noise ratio and also at each microphone angle to be used to analyse static engine noise data. Locate a reference near-field microphone on the centreline of and within 0.6 m (or 2 ft) of the acoustic centre of the acoustic driver(s);

b) energize the acoustic driver with pink noise without the ICD in place. Record the noise for a minimum of 60-second duration following system stabilization. The procedure must be conducted at a constant input voltage to the acoustic driver(s);

c) repeat item b), alternately with and without the ICD in place. A minimum of three tests of each configuration (with and without ICD in place) is required. To be acceptable, the total variation of the 55° microphone on-line OASPL signal (averaged for a 1-minute duration) for all three test conditions of each configuration shall not exceed 0.5 dB;

*Note.— Physically moving the ICD alternately in and out of place for this calibration may be eliminated if it is demonstrated that the ICD positioning does not affect the calibration results.*

d) all measured data are to be adjusted for sound pressure level variations as measured with the near-field microphone and for atmospheric absorption to 25°C and 70 per cent relative humidity (RH) conditions by using the slant distance between the outer microphones and the acoustic driver(s);

e) the calibration for each one-third octave band at each microphone is the difference between the average of the adjusted one-third octave band sound pressure levels (SPL) without the ICD in place and the average of the adjusted one-third octave band sound pressure levels with the ICD in place; and

f) the tests must be conducted under wind and thermal conditions that preclude acoustic shadowing at the outer microphones and weather-induced variations in the measured sound pressure level data. (Refer to Figure 2-5 and 2.3.3.7.)

In some cases large fluctuations in the value of the calibrations across adjacent one-third octave bands and between closely spaced angular positions of microphones can occur. These fluctuations can be related to reflection effects caused by the calibration procedure and care must be taken to ensure that they do not introduce or suppress engine tones. This may be done by comparing EPNLs computed with:

a) the ICD calibrations as measured;

b) a mean value of the calibration curves; and

c) the calibration values set to zero.

### 2.3.3.5 *Measurement and analysis systems*

Measurement and analysis systems used for static test and the modus operandi of the test programme may well vary according to the specific test objectives, but in general they should conform with those outlined in SAE ARP 1846. Some important factors to be taken into account are highlighted in subsequent sections.

### 2.3.3.6 *Microphone locations*

2.3.3.6.1 Microphones should be located over an angular range sufficient to include the 10 dB-down times after projection of the static noise data to flight conditions. The general guidance in SAE ARP 1846, describing microphone locations is sufficient to ensure adequate definition of the engine noise source characteristics.

2.3.3.6.2 The choice of microphone location with respect to the test surface depends on the specific test objectives and the methods to be used for data normalization. Certification experience with static engine testing has been primarily limited to microphone installations near the ground or at engine centreline height. In general, because of the difficulties associated with obtaining free-field sound pressure levels that are often desirable for extrapolating to flight conditions, near-ground-plane microphone installations or a combination of ground-plane and elevated microphones have been used. Consistent microphone locations, heights, etc. are recommended for noise measurements of both the prior approved and changed version of an engine or nacelle.

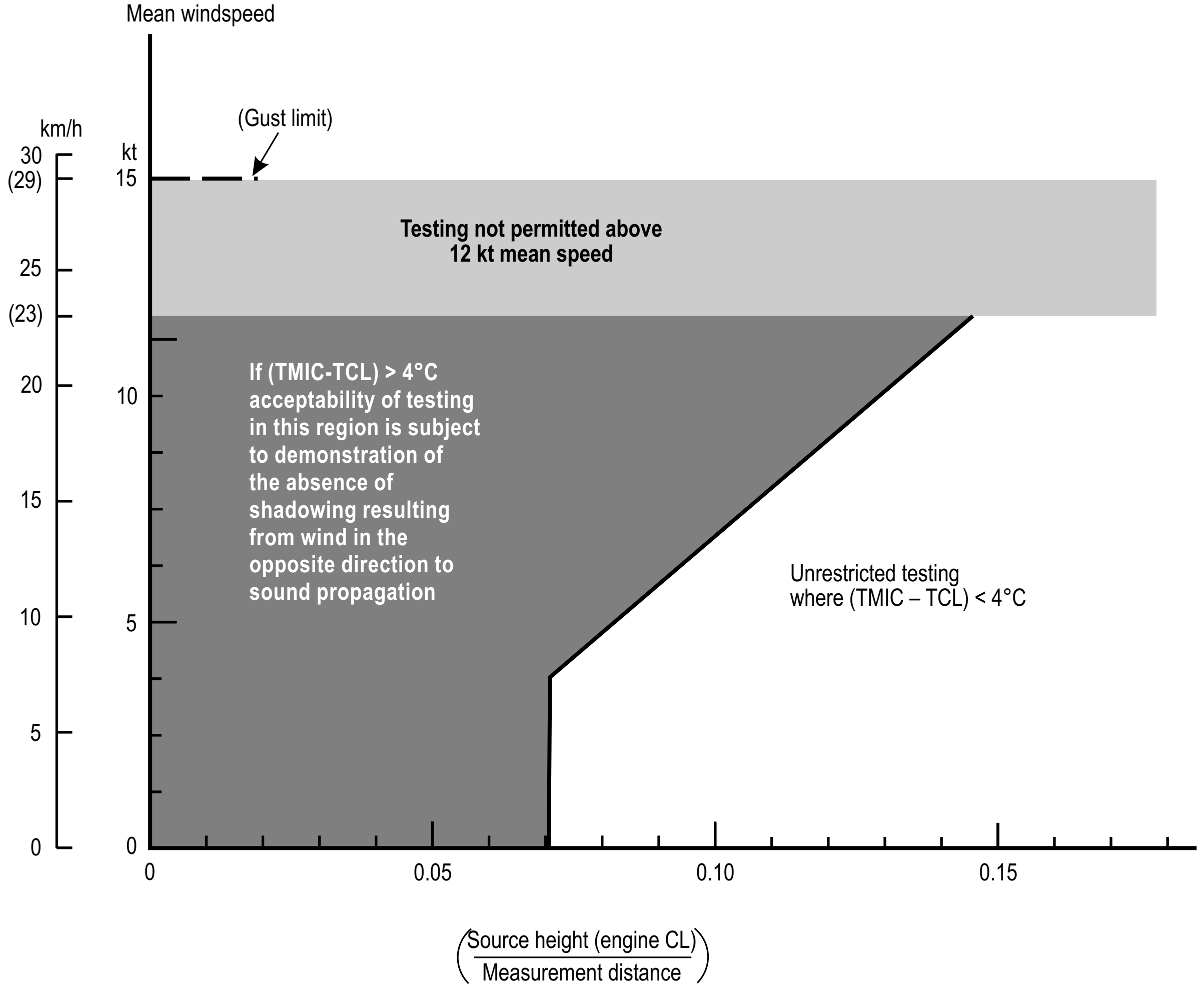
### 2.3.3.7 *Acoustic shadowing*

2.3.3.7.1 Where ground plane microphones are used, special precautions are necessary to ensure that consistent measurements (e.g. free from “acoustic shadowing” (refraction) effects) will be obtained. When there is a wind in the opposite direction to the sound wave propagating from the engine, or when there is a substantial thermal gradient in the test arena, refraction can influence near ground plane microphone measurements to a larger degree than measurements at greater heights.

2.3.3.7.2 Previous evidence or data from a supplemental test may be used to demonstrate that testing at a particular test site results in consistent measurements, including the absence of shadowing. In lieu of this evidence, a supplemental noise demonstration test should include an approved method to indicate the absence of shadowing effects on the ground-plane measurements.

2.3.3.7.3 The following criteria are suggested for certain test geometries, based on measurements of three weather parameters as follows:

- average wind speeds at engine centreline height (WCL);
- air temperature at engine centreline height (TCL); and
- air temperature at near ground plane microphone height (TMIC).



*Definition*

TCL = Temperature at engine centre line height

TMIC = Temperature within ± 5 mm of ground microphone diaphragm height

**Figure 2-5. Weather criteria for use with ground microphone installations**

The criteria are:

a) the instruments for these measurements should be co-located and placed close to the 90° noise measurement position without impeding the acoustic measurement;

b) the suggested limits are additional to the wind and temperature limits established by other criteria (such as the maximum wind speed at the microphone if wind screens are not used); and

c) wind and temperature criteria that have been observed to provide consistent measurements that preclude any influence of acoustic shadowing effects on ground-plane measurements are defined in Figure 2-5.

2.3.3.7.4 Figure 2-5 defines a boundary between the absence of shadowing and the possible onset of spectral deficiencies in the very high frequencies. Testing is permitted provided that the test day conditions are such that the average (typically 30 second) wind speed at engine centreline height falls below the line shown, and that wind gusting does not exceed the value of the line shown by more than 5.5 km/h (3 kt). Wind speeds in excess of the linear relationship shown, between 7 and 22 km/h (4 and 12 kt), may indicate the need to demonstrate the absence of spectral abnormalities, either prior to or at the time of test when the wind direction opposes the direction of sound propagation.

2.3.3.7.5 When the temperature at the ground microphone height is not greater than the temperature at the engine centreline height plus 4°K, shadowing effects due to temperature gradients can be expected to be negligible.

*Note.— Theoretical analyses and the expression of wind criteria in terms of absolute speed rather than the vector reduction suggest that the noted limits may be unduly stringent in some directions.*

2.3.3.8 *Engine power test conditions*

A range of static engine operating conditions should be selected to correspond to the expected maximum range of in-flight engine operating conditions for the appropriate engine power setting parameter. A sufficient number of stabilized engine power settings over the desired range should be included in the test to ensure that the 90 per cent confidence intervals for values of flight-projected EPNL can be established (see Section 3 of Appendix 1 to this manual).

2.3.3.9 *Data system compatibility*

2.3.3.9.1 If more than one data acquisition system and/or data analysis system is used for the acquisition or analysis of static data, compatibility of the airframe and engine manufacturers' systems is necessary. Compatibility of the data acquisition systems can be accomplished through appropriate calibration. Compatibility of the data analysis systems can be verified by analysing the same data samples on both systems. The systems are compatible if the resulting differences are no greater than 0.5 EPNdB. Evaluation should be conducted at flight conditions representative of those for certification.

2.3.3.9.2 The use of pseudo-random noise signals with spectral shape and tonal content representative of turbofan engines is an acceptable alternative to the use of actual engine noise measurements for determining analysis system compatibility. The systems are compatible if the resulting differences are no greater than 0.5 PNdB for an integration time of 32 seconds.

2.3.3.10 *Data acquisition, analysis and normalization*

For each engine power setting designated in the test plan, the engine performance, meteorological and sound pressure level data should be acquired and analysed using instrumentation and test procedures described in SAE ARP 1846. Sound measurements should be normalized to consistent conditions and include 24 one-third octave band sound pressure levels between band centre frequencies of 50 Hz to 10 kHz for each measurement (microphone) station. Before projecting the static engine data to flight conditions, the sound pressure level data should be corrected for:

a) the frequency response characteristics of the data acquisition and analysis system; and

b) contamination by background ambient or electrical system noise. (See Appendix 3 of this manual).

### 2.3.4 Projection of static engine data to aeroplane flight conditions

2.3.4.1 *General*

2.3.4.1.1 The static engine sound pressure level data acquired at each angular location should be analysed and normalized to account for the effects identified in 2.3.3.10.

They should then be projected to the same aeroplane flight conditions used in the development of the approved NPD plot.

2.3.4.1.2 As appropriate, the projection procedure includes:

a) the effects of source motion including Doppler effects;

b) the number of engines and shielding effects;

c) the installation effects;

d) the flight geometry;

e) the atmospheric propagation, including spherical wave divergence and atmospheric attenuation; and

f) the flight propagation effects including ground reflection and lateral attenuation. (See 2.3.4.11).

2.3.4.1.3 To account for these effects, the measured total static noise data should be analysed to determine contributions from individual noise sources. After projecting the one-third octave-band spectral data to flight conditions, EPNLs should be calculated for the revised NPD plot. Guidelines on the elements of an acceptable projection procedure are provided in this section. The process is also illustrated in Figures 2-6 and 2-7.

2.3.4.1.4 It is not intended that the procedure illustrated in Figures 2-6 and 2-7 should be exclusive. There are several options, depending upon the nature of the powerplant noise sources and the relevance of individual noise sources to the EPNL of the aeroplane. The method presented does, however, specify the main features that should be considered in the computational procedure.

2.3.4.1.5 It is also not necessary that the computations illustrated in Figures 2-6 and 2-7 should always be carried out in the order specified. There are interrelations between the various steps in the procedure which depend on the particular form of the computation being followed. Hence the most efficient manner of structuring the computation cannot always be pre-determined.

2.3.4.1.6 There are several engine installation effects which can modify the generated noise levels but which cannot be derived from static tests. Additional noise sources such as jet/flap or jet/wind interaction effects may be introduced on a derived version of the aeroplane which are not present on the "flight datum" aeroplane. Far-field noise directivity patterns (field shapes) may be modified by wing/nacelle or jet-by-jet shielding, tailplane and fuselage scattering or airframe reflection effects. However, general methods to adjust for these effects are not yet available. It is therefore important that, before the following procedures are approved for the derived version of the aeroplane, the geometry of the airframe and engines in the vicinity of the engines be shown to be essentially identical to that of the "flight datum" aeroplanes so that the radiated noise is essentially unaffected.

### 2.3.4.2 *Normalization to reference conditions*

2.3.4.2.1 The analysed one-third octave band sound pressure level static test data should be normalized to free-field conditions in the Annex 16, Volume I reference atmosphere. This adjustment can only be applied with a knowledge of the total spectra being the summation of all the noise source spectra computed as described in 2.3.4.3 to 2.3.4.5.

2.3.4.2.2 The required adjustments include:

a) *Atmospheric absorption.* Adjustments to account for the acoustical reference day atmospheric absorption are defined in SAE ARP 866A (revised 15 March 1975). In the event that minor differences in absorption values are found in SAE ARP 866A between equations, tables or graphs, the equations should be used. The atmospheric absorption should be computed over the actual distance from the effective centre of each noise source to each microphone, as determined in 2.3.4.5; and

b) *Ground reflection.* Examples of methods for obtaining free-field sound pressure levels are described in SAE AIR 1672B-1983 or in Engineering Sciences Data Unit (ESDU) Item 80038, Amendment A. Spatial distribution of noise sources do not have a first order influence on ground reflection effects and hence may be disregarded. It is also noted that measurements of far-field sound pressure levels with ground-plane microphones may be used to avoid the large spectral irregularities caused by interference effects at frequencies less than 1 kHz.

### 2.3.4.3 *Separation into broadband and tone noise*

2.3.4.3.1 The purpose of procedures described in this section is to identify all significant tones in the spectra,

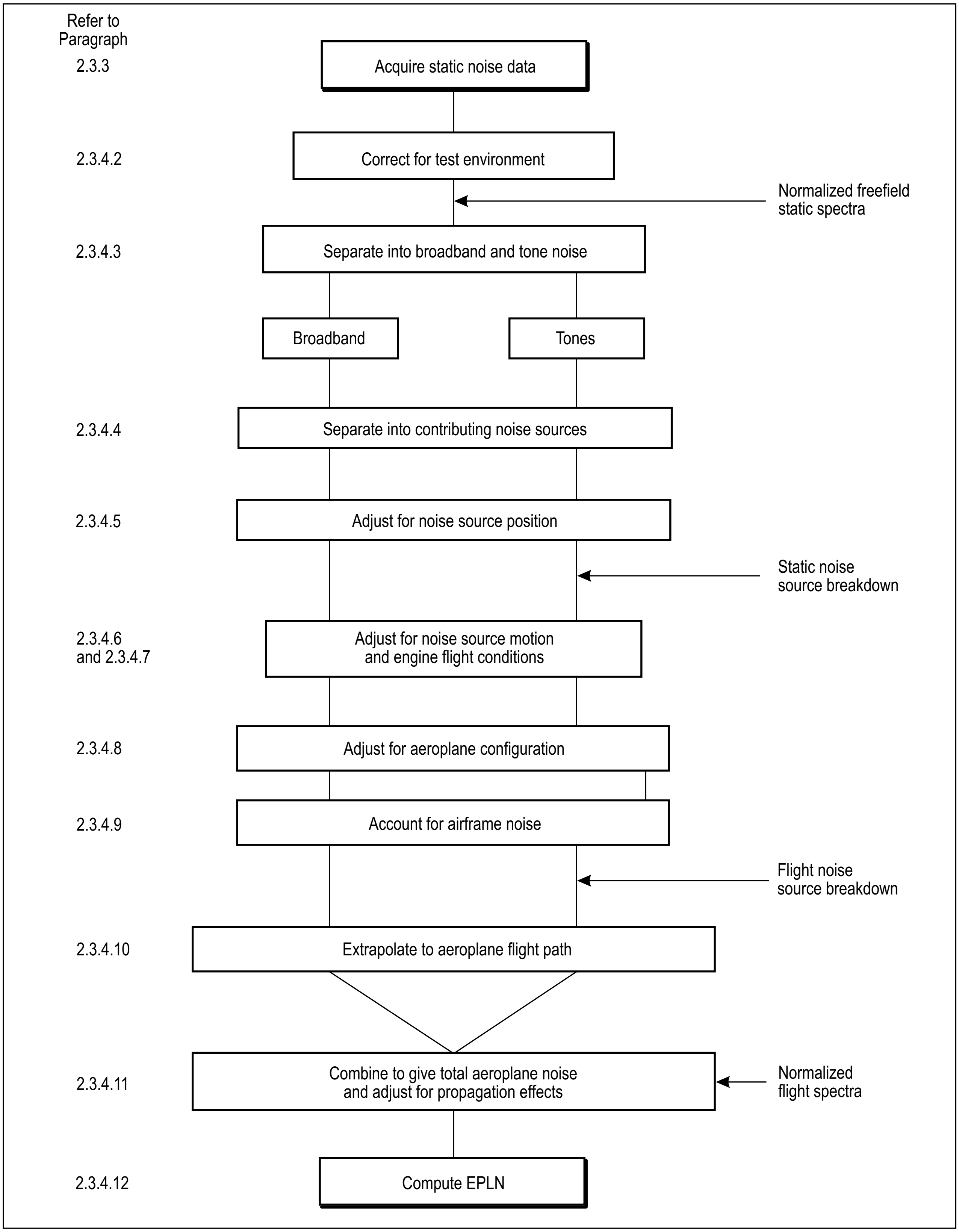


**Figure 2-6. Generalized projection of static engine data to aeroplane flight conditions**

firstly to ensure that tones are not included in the subsequent estimation of broadband noise, and secondly to enable the Doppler-shifted tones (in-flight) to be allocated to the correct one-third octave band at appropriate times during a simulated aeroplane flyover.

2.3.4.3.2 Broadband noise should be derived by extracting all significant tones from the measured spectra. One concept for the identification of discrete tones is the one used in Annex 16, Volume I, Appendix 2 for tone correction purposes (that is, considering the slopes between adjacent one-third octave band levels). Care must be taken to avoid regarding tones as "non protrusive" when the surrounding broadband sound pressure level is likely to be lower when adjusted from static to flight conditions, or when classifying a closely grouped pair or series of tones as broadband noise. One technique for resolving such problems is the use of narrow band analysis with a bandwidth of less than 50 Hz.

2.3.4.3.3 Narrow band analysis can also be used to check the validity of other tone identification procedures in establishing the spectral character at critical locations in the sound field (e.g. around the position of peak PNLT) or where predominant turbo-machinery tones exist.

### 2.3.4.4 *Separation into contributing noise sources*

2.3.4.4.1 The number of noise sources which require identification will to some extent depend on the engine being tested and the nature of the change to the engine or nacelle. The separation of broadband noise into the combination of noise generated by external jet mixing and by internal noise sources is the minimum and sometimes adequate requirement. A more sophisticated analysis may be necessary depending upon the significance of the contribution from other individual sources, which could involve identifying broadband noise from fan, compressor, combustor and turbine. Furthermore, for fan and compressor noise, the split of both the broadband and the tone noise between that radiating from the engine intake and that from the engine exhaust nozzle(s) could be a further refinement.

2.3.4.4.2 To meet the minimum requirement, the separation of sources of broadband noise into those due to external jet mixing and those generated internally can be carried out by:

a) estimating the jet noise by one or more of the methods identified in 2.3.4.4.3, and

b) adjusting the level of the predicted spectrum at each angle to fit the measured low frequency part of the broadband spectrum at which jet noise can be expected to be dominant.

2.3.4.4.3 There are three methods which have been used to obtain predicted jet noise spectra shapes:

a) for single-stream engines with circular nozzles, the procedure detailed in SAE ARP 876C-1985 may be used. The engine geometry however may possess features which can render this method inapplicable. Sample procedures for coaxial flow engines are provided in SAE AIR 1905-1985;

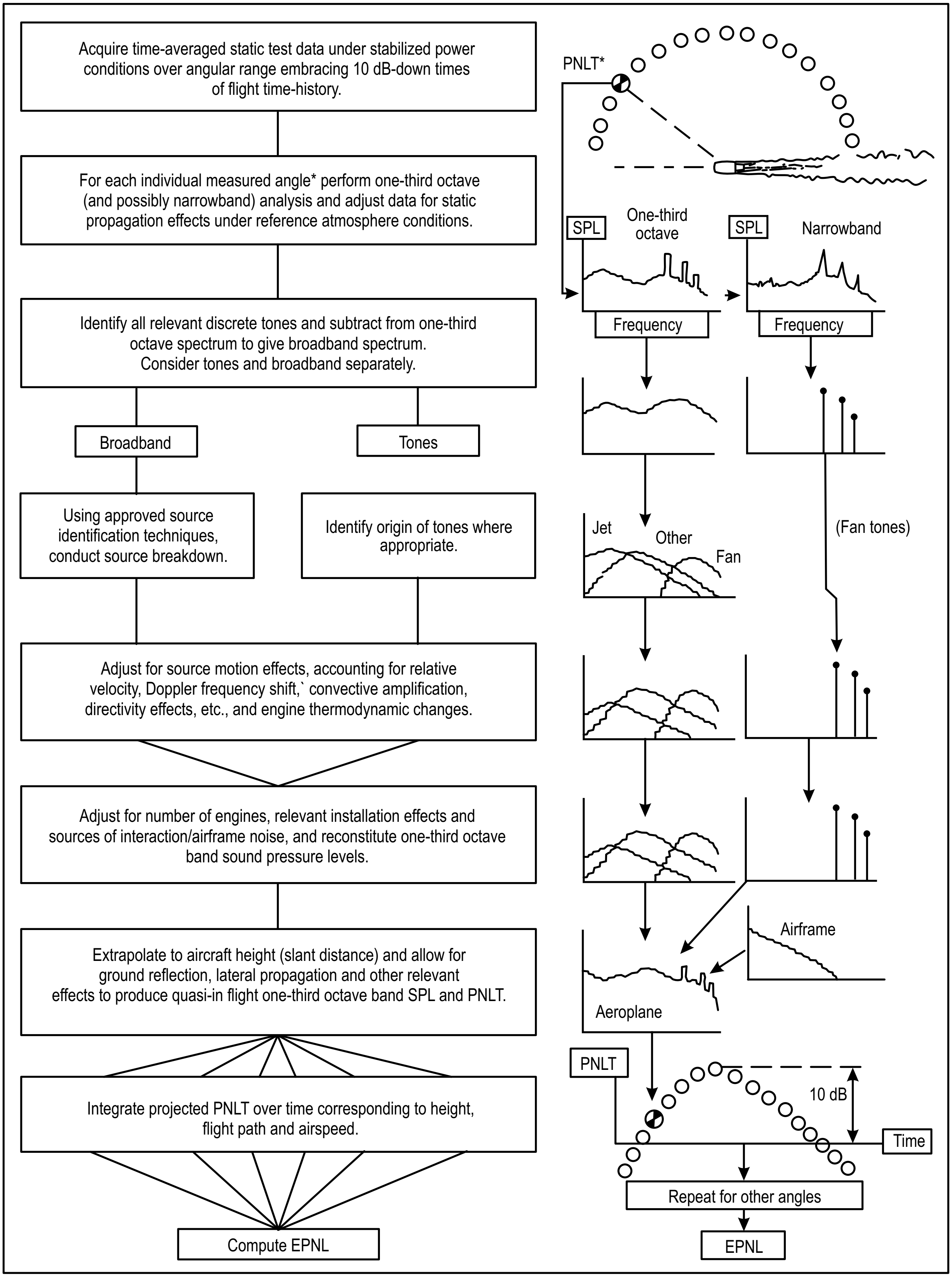
b) analytical procedures based on correlating full-scale engine data with model nozzle characteristics may be used. Model data have been used to supplement full-scale engine data, particularly at low power settings, because of the uncertainty in defining the level of jet noise at the higher frequencies where noise from other engine sources may make a significant contribution to the broadband noise; and

c) special noise source location techniques are available which, when used during full-scale engine tests, can identify the positions and levels of separate engine noise sources.

### 2.3.4.5 *Noise source position effects*

2.3.4.5.1 Static engine noise measurements are often made at distances at which engine noise sources cannot be truly treated as radiating from a single acoustic centre. This may not give rise to difficulties in the extrapolation to determine the noise increments from static data to flight conditions because noise increments in EPNL are not particularly sensitive to the assumption made regarding the spatial distribution of noise sources.

2.3.4.5.2 However, in some circumstances (for example, where changes are made to exhaust structures and where the sources of external jet-mixing noise are of overriding significance), it may be appropriate to identify noise source positions more accurately. The jet noise can be considered as a noise source distributed downstream of the engine exhaust plane. Internal sources of broadband engine noise may be considered as radiating from the intake and the exhaust.



Acquire time-averaged static test data under stabilized power conditions over angular range embracing 10 dB-down times of flight time-history.

For each individual measured angle* perform one-third octave (and possibly narrowband) analysis and adjust data for static propagation effects under reference atmosphere conditions.

Identify all relevant discrete tones and subtract from one-third octave spectrum to give broadband spectrum. Consider tones and broadband separately.

Using approved source identification techniques, conduct source breakdown.

Identify origin of tones where appropriate.

Adjust for source motion effects, accounting for relative velocity, Doppler frequency shift,` convective amplification, directivity effects, etc., and engine thermodynamic changes.

Adjust for number of engines, relevant installation effects and sources of interaction/airframe noise, and reconstitute one-third octave band sound pressure levels.

Extrapolate to aircraft height (slant distance) and allow for ground reflection, lateral propagation and other relevant effects to produce quasi-in flight one-third octave band SPL and PNLT.

Integrate projected PNLT over time corresponding to height, flight path and airspeed.

Figure 2-7. Example procedure for projection of static engine data to aeroplane flight conditions

2.3.4.5.3 There are three principal effects to be accounted for as a consequence of the position of the noise source differing from the "nominal" position assumed for the "source" of engine noise:

a) *Spherical divergence*. The distance of the source from the microphone differs from the nominal distance; an inverse square law adjustment needs to be applied;

b) *Directivity.* The angle subtended by the line from the source to the microphone and the source to the engine centreline differs from the nominal angle; a linear interpolation should be made to obtain data for the proper angle; and

c) *Atmospheric attenuation*. The difference between the true and the nominal distance between the source and the microphone alters the allowance made for atmospheric attenuation in 2.3.4.2.

2.3.4.5.4 Source position can be identified either from noise source location measurements (made either at full or model scale) or from a generalized database.

*Note.— No published standard on coaxial jet noise source distribution is currently available. An approximate distribution for a single jet is given by the following equation (see items 1 and 2 in the References section of this manual):*

$$x/D = (0.057S + 0.021S^2)^{-1/2}$$

*where:*

*S is the Strouhal number* $fD/V_j$;

*x is the distance downstream from the nozzle exit;*

*D is the nozzle diameter based on total nozzle exit area;*

$V_j$ *is the average jet velocity for complete isentropic expansion to ambient pressure from average nozzle-exit pressure and temperature; and*

*f is the one-third octave band centre frequency.*

### 2.3.4.6 *Engine flight conditions*

2.3.4.6.1 Some thermodynamic conditions within an engine tested statically differ from those that exist in flight; this difference should be taken into account. Noise source strengths may be changed accordingly. Therefore, the values for key correlating parameters for component noise source generation should be based on the flight condition and the static database should be entered at the appropriate correlating parameter value. Turbo-machinery noise levels should be based on the in-flight corrected rotor speeds $N_1/\sqrt{\theta_{t2}}$ and jet noise levels should be based on the relative jet velocities that exist at the flight condition.

2.3.4.6.2 The variation of source noise levels with key correlating parameters can be determined from the static database which includes a number of different thermodynamic operating conditions.

### 2.3.4.7 *Noise source motion effects*

The effects of motion on jet noise differ from speed effects on other noise sources, and hence are considered separately during static-to-flight projection.

#### 2.3.4.7.1 External jet noise

Account should be taken of the frequency-dependent jet relative velocity effects and the convective amplification effects. Broadly speaking, two sources of information may be used to develop an approved method for defining the effect of flight on external jet noise:

a) for single-stream engines with circular exhaust geometries, SAE ARP 876C-1985 provides guidance. Additional supporting evidence however may be needed to show when jet noise is the major contributor to the noise from an engine with a more complex nozzle assembly; and

b) full-scale flight data on a similar exhaust geometry can provide additional evidence. In general, however, because of the difficulty of defining high frequency effects in the presence of internally-generated engine noise, it may be necessary to provide additional supporting information to determine the variation of EPNL, with changes of jet noise spectra at high frequencies.

#### 2.3.4.7.2 Noise sources other than jet noise

In addition to the Doppler frequency effect on the non-jet noise observed on the ground from an aeroplane flyover, the noise generated by the engine's internal components and the airframe can be influenced by source amplitude modification and directivity changes.

a) *Doppler effect.* Frequency shifting that results from motion of the source (aeroplane) relative to a microphone is accounted for by the following equation:

$$f_{flight} = \frac{f_{static}}{(1 - M\cos\lambda)}$$

where:

$f_{flight}$ = flight frequency;

$f_{static}$ = static frequency;

$M$ = Mach number of aeroplane; and

$\lambda$ = angle between the flight path in the direction of flight and a straight line connecting the aeroplane and the microphone at the time of sound emission.

It should be noted for those one-third octave band sound pressure levels dominated by a turbo-machinery tone, the Doppler shift may move the tone (and its harmonics) into an adjacent band.

b) *Source amplitude modification and directivity changes*. One-third octave band sound pressure level adjustments to airframe-generated noise that results from speed changes between the datum and derivative version is provided for in 2.3.4.9 on airframe noise.

For noise generated internally within the engine (e.g. fan noise), there is no consensus of opinion on the mechanisms involved or on a unique adjustment method that accounts for the detailed source modification and sound propagation effects.

If an adjustment is used, the same technique must be applied to both the flight datum and derivative configuration when establishing noise changes. In such instances the adjustment for the one-third octave band sound pressure level changes that result from the motion of the source (aeroplane) relative to the microphone may be accounted for by using the following equation:

$$SPL_{flight} = SPL_{static} - K \log (1 - M\cos \lambda)$$

where:

$SPL_{flight}$ = flight sound pressure level;

$SPL_{static}$ = static sound pressure level; and

$M$ and $\lambda$ are defined above and $K$ is a constant.

Theoretically, $K$ has a value of 40 for a point noise source but a more appropriate value may be obtained by comparing static and flight data for the "flight datum" aeroplane.

### 2.3.4.8 *Aeroplane configuration effects*

2.3.4.8.1 The contribution from more than one engine on an aeroplane is normally taken into account by adding *10* log *N*, where *N* is the number of engines, to each component noise source. It might be necessary however to compute the noise from engines widely spaced on large aeroplanes, particularly in the approach case, if they include both underwing and fuselage mountings. The noise from the intakes of engines mounted above the fuselage is known to be shielded.

2.3.4.8.2 If engine installation effects change between the "flight datum" aeroplane and a derived version, account should be taken of the change on one-third octave band sound pressure levels which should be estimated according to the best available evidence.

### 2.3.4.9 *Airframe noise*

2.3.4.9.1 To account for the contribution of airframe noise, measured flight datum airframe noise on its own or combined with an approved airframe noise analytical model may be used to develop an airframe noise database. The airframe-generated noise, which can be treated as a point source for adjustment purposes, is normalized to the same conditions as those of the other (engine) sources, with due account given for the effects of spherical divergence, atmospheric absorption and airspeed as described in Sections 8 and 9 of Appendix 2 of Annex 16, Volume I.

2.3.4.9.2 Airframe noise for a specific configuration varies with airspeed (see item 3 in the References section of this manual) as follows:

$$\Delta SPL_{airframe} = 50 \log (V_{REF}/V_{TEST})$$

where:

$V_{REF}$ is the approved reference airspeed for the "flight datum" aeroplane; and

$V_{TEST}$ is model or measured airspeed.

2.3.4.9.3 The above equation is also valid for adjustments to EPNL where an empirically derived coefficient replaces the coefficient 50 since that number may be somewhat configuration-dependent. However, the approval of the certification authority is required for values other than 50.

### 2.3.4.10 *Aeroplane flight path considerations*

When computing the one-third octave band sound pressure levels corresponding to the slant distance of the aeroplane in flight from the noise measuring point, the principal effects are spherical divergence (inverse square law adjustments from the nominal static distance) and atmospheric attenuation (as described in Sections 8 and 9 of Appendix 2 of Annex 16, Volume I). Furthermore, account should be taken of the difference between the static engine axis and that axis in flight relative to the reference noise measuring points. The adjustments should be applied to the component noise source levels that have been separately identified.

### 2.3.4.11 *Total noise spectra*

2.3.4.11.1 Both the engine tonal and broadband noise source components in flight, together with the airframe noise and any installation effects, are summed up on a mean-square pressure basis to construct the spectra of total aeroplane noise levels.

2.3.4.11.2 During the merging of broadband and tonal components, consideration should be given to appropriate bandsharing of discrete frequency tones.

2.3.4.11.3 The effects of ground reflections must be included in the estimate of free-field sound pressure levels in order to simulate the sound pressure levels that would be measured by a microphone at a height of 1.2 m above a natural terrain. Information in SAE AIR 1672B-1983 or ESDU data item 80038, Amendment A may be used to apply adjustments to the free-field spectra to allow for flight measurements being made at 1.2 m (4 ft). Alternatively, the ground reflection adjustment can be derived from other approved analytical or empirically derived models. Note that the Doppler adjustment for a static source at frequency ($f_{static}$) applies to a moving (aeroplane) source at a frequency ($f_{flight}$) where $f_{flight} = f_{static} /(1 - M\cos \lambda)$ using the terminology of 2.3.4.7.2a). This process is repeated for each measurement angle and for each engine power setting.

2.3.4.11.4 With regard to lateral attenuation, the information in SAE AIR 1751-1981 applicable to the computation of lateral noise may be applied.

### 2.3.4.12 *EPNL computations*

For EPNL calculations, a time is associated with each extrapolated spectrum along the flight path. (Note that the time is associated with each measurement location with respect to the engine/aeroplane reference point and the aeroplane's true airspeed along the reference flight path, assuming zero wind). For each engine power setting and minimum distance, an EPNL is computed from the projected time history using the methods described in Annex 16, Volume I, Appendices 1 and 2.

### 2.3.4.13 *Changes to noise levels*

2.3.4.13.1 An NPD plot can be constructed from the projected static data for both the original (flight datum) and the changed configurations of the engine or nacelle tested. Comparisons of the noise versus engine thrust (power) relationships for the two configurations at the same appropriate minimum distance will determine whether or not the changed configuration resulted in a change to the noise level from an engine noise source. If there is a change in the level of source noise, a new in-flight aeroplane NPD plot can be developed by adjusting the measured original NPD plot by the amount of change indicated by the comparison of the static-projected NPD plots for the original and changed versions within the limitations specified in 2.3.2 for EPNL.

2.3.4.13.2 The noise certification levels for the derived version of an aeroplane may be determined from NPD plots at the relevant reference engine power and distance, with an additional adjustment of [$10 \log V_{nom}/V_r$] for the velocity of the aeroplane at the certification reference condition relative to the nominal velocity ($V_{nom}$) used in developing the NPD plots.

# Chapter 3

# EQUIVALENT PROCEDURES FOR PROPELLER-DRIVEN AEROPLANES OVER 8 618 KG

The procedures described in this chapter have been used as equivalent in stringency for propeller-driven aeroplanes with maximum certificated take-off mass exceeding 8 618 kg, as provided in Chapter 3 and Chapter 5 of Annex 16 — *Environmental Protection*, Volume I — *Aircraft Noise*.

## 3.1 FLIGHT TEST PROCEDURES

### 3.1.1 Flight path intercept procedures

Flight path intercept procedures, as described in 2.1.1 of this manual, have been used to meet the demonstration requirements of noise certification, in lieu of full take-offs and/or landings.

### 3.1.2 Generalized flight test procedures

Generalized flight test procedures (other than normal noise demonstration take-offs and approaches) have been used to meet two equivalency objectives:

a) *To acquire noise data over a range of engine power settings at one or more heights.* This information permits the development of generalized noise characteristics necessary for the certification of a "family" of similar aeroplanes. The procedures used are similar to those described in 2.1.2.1, with the exception that the noise-power-distance (NPD) plots employ engine noise performance parameters ($\mu$) of propeller helical tip Mach number ($M_H$) and shaft horsepower ($SHP/\delta_{amb}$) (see Figure 3-1), where $\delta_{amb}$ is defined in 2.1.2.1.4. In order to ensure that propeller inflow angles are similar throughout the development of the noise-sensitivity data as the aeroplane mass changes, the airspeed of the aeroplane used in the flight tests for developing the lateral and flyover data shall be $V_2$ + *19 km/h* ($V_2$ + *10 kt*) to within ±6 km/h or ±3 kt, as appropriate for the mass of the aeroplane during the test. For the development of the NPD data for the approach case, the speed and approach angle constraints imposed in 3.6.3, 3.7.5, 4.5, 4.6, 5.6.3b) and 5.7.5 of Chapters 3, 4 and 5 respectively of Annex 16, Volume I cannot be satisfied over the typical range of power needed. For the approach case, a steady speed of $V_{REF}$ + *19 km/h* ($V_{REF}$ + *10 kt*) should be maintained to within ±6 km/h or ±3 kt and the flyover height over the microphone should be 122 m ± 30 m (400 ft ± 100 ft). Within these constraints, the test approach angle at the test power should be that which results from the test aeroplane conditions, i.e. mass, configuration, speed and power.

b) *To determine noise level changes by comparisons of flyover noise test data for different developments of an aeroplane type* (e.g. a change in propeller type). Such changes are used to establish certification noise levels of a newly derived version as described in 2.1.2.2.

### 3.1.3 Determination of the lateral noise certification level

3.1.3.1 For propeller-driven aeroplanes, Amendment 5 of Annex 16, Volume I introduced into Chapter 3 a full-power measurement point under the flight path as a replacement for the lateral measurement point. However, for those aeroplanes for which the 2-microphone lateral measurement method was applicable, this section describes appropriate equivalent procedures.

3.1.3.2 Determination of the lateral noise certification level employing an alternative procedure using two microphone stations located symmetrically on either side of the take-off flight path similar to that as described in 2.1.3 of this manual has been approved. However, when this procedure is used, matching data from both lateral microphones for each fly-by must be used for the lateral noise determination; cases where data from only one microphone is available for a given fly-by must be omitted from the determination. The following paragraphs describe the procedures for propeller-driven heavy aeroplanes.

a) The lateral Effective Perceived Noise Level (EPNL) from propeller-driven aeroplanes, when plotted against height opposite the measuring sites, can exhibit distinct asymmetry. The maximum EPNL on one side of the aeroplane is often at a different height and noise level from that measured on the other side.

b) In order to determine the average maximum lateral EPNL, i.e. the certification sideline noise level, it is therefore necessary to undertake a number of flights over a range of heights to define the noise versus height characteristics for each side of the aeroplane. A typical height range would cover between 30 m (100 ft) and 550 m (1 800 ft) above a track at right angles to and midway along the line joining the two microphone stations. The intersection of the track with this line is defined as the reference point.

c) Since experience has shown the maximum lateral noise level may often be near the lower end of this range a minimum of six good sets of data, measured simultaneously from both sides of the flight track, should be obtained for a range of aeroplane heights as low as possible. In this case take-offs may be necessary; however care should be taken to ensure that the airspeed is stabilized to at least $V_2$ + *19 km/h* ($V_2$ + *10 kt*) over the 10 dB-down time period.

d) The aeroplane climbs over the reference point using take-off power, speeds and configuration as described in 3.6.2.1 c) and d) of Chapter 3 or 5.6.2.1 c) and d) of Chapter 5 of Annex 16, Volume I.

e) The lateral certification noise level is obtained by finding the peak of the curve of noise level (EPNL)

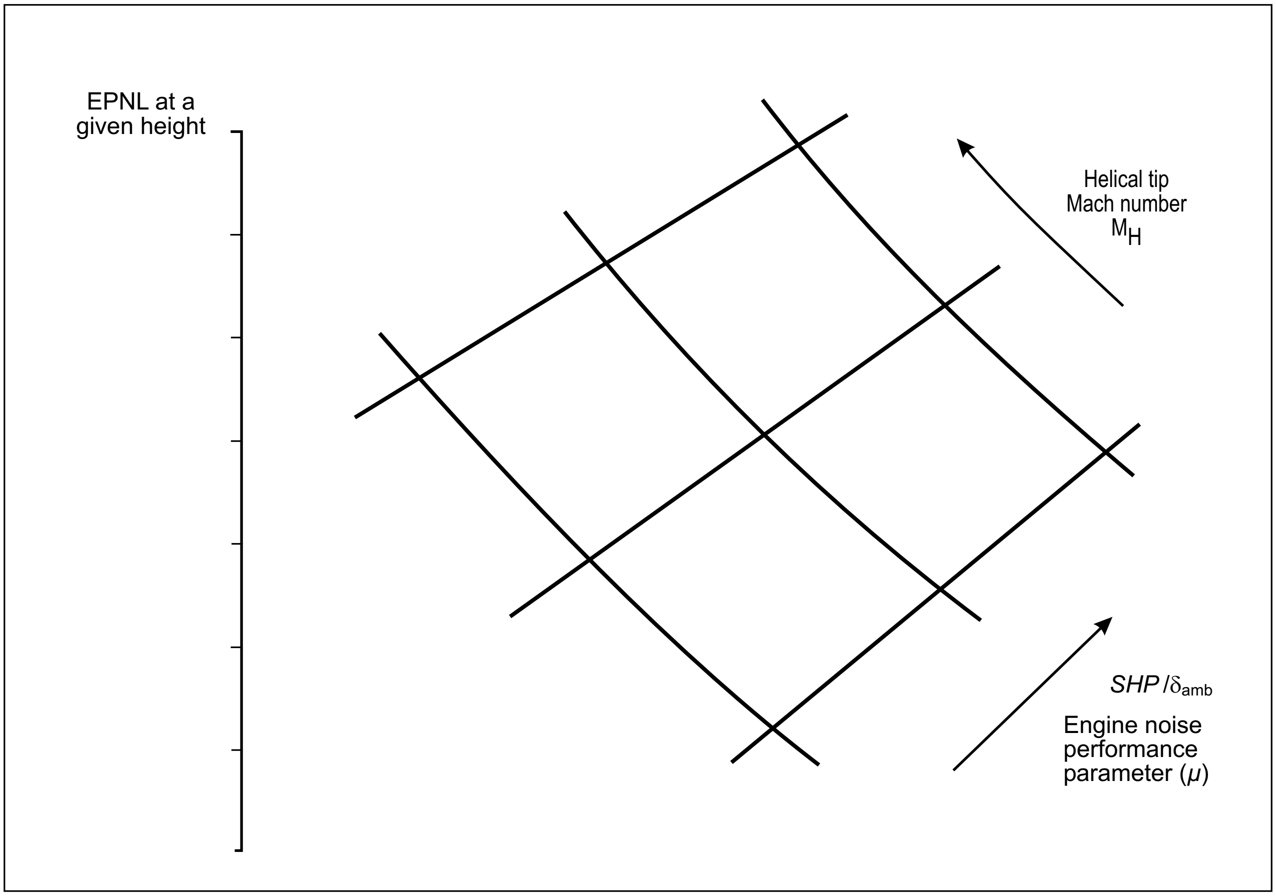


**Figure 3-1. Form of noise-power-distance (NPD) plot for heavy propeller-driven aeroplanes**

corrected to reference day atmospheric absorption values and plotted against aeroplane height above the reference point (see Figure 3-2). This curve is described as a least squares curve fit through the data points defined by the median values of each pair of matched data measured on each side of the track (i.e. the average of the two microphone measurements for a given aeroplane height).

f) To ensure that the requirements of 5.5.2 of Appendix 1 or 5.4.2 of Appendix 2 of Annex 16, Volume I are met, the 90 per cent confidence limits should be determined in accordance with 2.2 of Appendix 1 of this manual.

### 3.1.4 Measurements at non-reference points

3.1.4.1 In some instances, test measurement points may differ from the reference measurement points as specified in Chapters 3 and 5 of Annex 16, Volume I. Under these circumstances, an applicant may request approval of data that have been adjusted from actual measurements to the reference conditions for reasons described in 2.1.5.2 a), b) and c) of this manual.

3.1.4.2 Noise measurements collected closer to the test aeroplane than at the certification reference points are particularly useful for correcting propeller noise data as

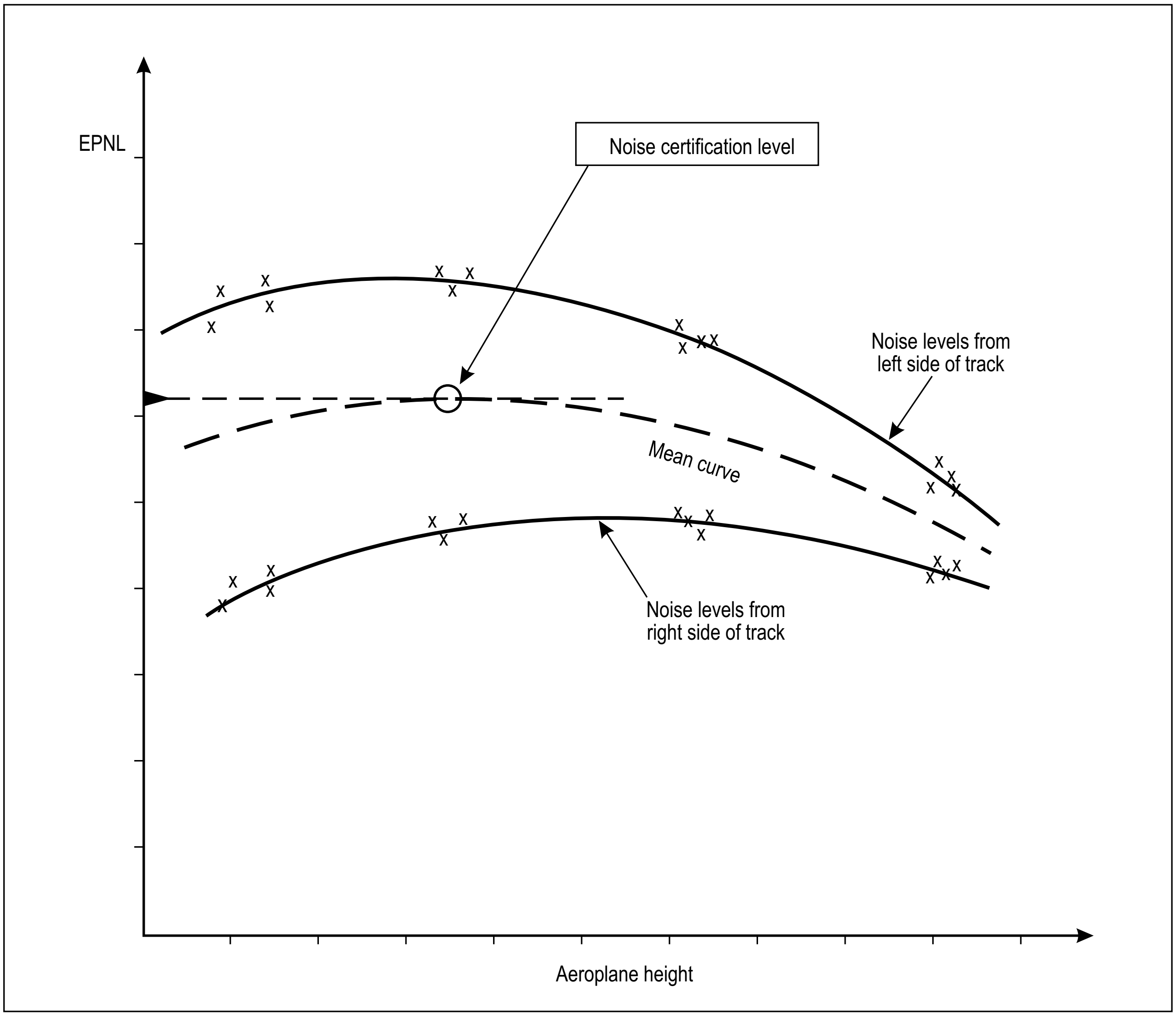


Figure 3-2. Typical lateral noise data plot for heavy propeller-driven aeroplane

they are dominated by low frequency noise. The spectra roll off rapidly at higher frequencies and are often lost in the background noise at frequencies above 5 000 Hz. Appendix 3 of this manual describes an alternative procedure.

3.1.4.3 Non-reference measurement points may be used provided that measured data are adjusted to reference conditions in accordance with the requirements of Section 9 of either Appendix 1 or Appendix 2 of Annex 16, Volume I and that the magnitude of the adjustments does not exceed the limits cited in 3.7.6 of Chapter 3 and 5.7.6 of Chapter 5 of Annex 16, Volume I.

## 3.2 ANALYTICAL PROCEDURES

3.2.1 Equivalent analytical procedures rely upon the available noise and performance data of the aeroplane type. The generalized relationships between noise levels, propeller helical tip Mach number, and shaft horsepower as well as the correction procedures for speed and height changes in accordance with the methods of Appendix 2 of Annex 16, Volume I are combined with certificated aeroplane performance data in order to determine noise level changes resulting from type design changes. The noise level changes are then added to or subtracted from the noise certification levels that are demonstrated by flight test measurements for the "flight datum" aeroplane.

3.2.2 Certifications using analytical procedures have been approved for type design changes that result in predictable noise level differences. The type design changes include the following:

a) an increase or decrease in maximum take-off and/or landing mass of the aeroplane from the originally certificated mass;

b) power increase or decrease for engines that are acoustically similar and fitted with propellers of the same type;

c) aeroplane, engine and nacelle configuration changes, usually minor in nature, including derivative aeroplane models with changes in fuselage length and flap configuration. Care is however needed to ensure that the existing noise sources are not modified by these changes (e.g. by changing the flow field into the propellers); and

d) minor airframe design changes that could indirectly affect noise levels because of an impact on aeroplane performance (e.g. increased drag). Changes in aeroplane performance characteristics derived from aerodynamic analysis or testing have been used to demonstrate how these changes can affect the aeroplane flight path and consequently the demonstrated noise levels of the aeroplane.

## 3.3 GROUND STATIC TESTING PROCEDURES

### 3.3.1 General

Unlike the case of a turbojet or turbofan powerplant, static tests involving changes to the propeller are not applicable for determining noise level changes in the development of a propeller-driven aeroplane/powerplant family because of changes in the aero-acoustic operating conditions of the propeller when run statically compared with conditions existing during flight. The propeller noise levels measured during a static test can include significant contributions from noise source components that are not normally important in flight. However, limited static tests on engines with propellers, which are used as engine loading devices, can be utilized to determine small noise changes, as described below.

### 3.3.2 Guidance on the test site characteristics

Guidance on the test site characteristics data acquisition and analysis systems, microphone locations, acoustical calibration and measurement procedures for static testing, is provided in SAE ARP 1846 and is equally valid in these respects for propeller powerplants.

### 3.3.3 Static tests of the gas generator

3.3.3.1 Static tests of the gas generator can be used to identify noise changes resulting from changes to the design of the gas generators or to the internal structure of the engine in the frequency ranges:

a) where there is a contribution to the aeroplane EPNL; or

b) where that part of the spectrum is clearly dominated by the gas generator; or

c) where ancillary equipment under circumstances where the propeller and its aerodynamic performance remains unchanged.

3.3.3.2 Such circumstances where the propeller and its aerodynamic performance remain unchanged include, for example, changes to the compressor, turbine or combustor of the powerplant. The effect of such changes should be conducted under the same test, measurement, data reduction and extrapolation procedures as described in 2.3 for turbojet and turbofan engines. The noise emanating from any propeller or other power extraction device used in static tests should be eliminated or removed analytically. For the purposes of aeroplane EPNL calculation, the measured "flight datum" aeroplane propeller contributions should be included in the computation process.

# Chapter 4

# EQUIVALENT PROCEDURES FOR PROPELLER-DRIVEN AEROPLANES NOT EXCEEDING 8 618 KG

The procedures described in this chapter have been used as equivalent in stringency for propeller-driven aeroplanes with maximum certificated take-off mass not exceeding 8 618 kg, as provided in Chapter 6 and Chapter 10 of Annex 16 — *Environmental Protection*, Volume I — *Aircraft Noise*.

## 4.1 SOURCE NOISE ADJUSTMENTS

Source noise adjustment data for propeller-driven light aeroplanes may be obtained by flying the test aeroplane with a range of propeller speeds (for fixed pitch propellers) and torque or manifold air pressure (MAP) values (for variable pitch propellers).

### 4.1.1 Fixed pitch propellers

4.1.1.1 For aeroplanes fitted with fixed pitch propellers, source noise sensitivity curves are developed from data taken by measuring the noise level for the aeroplane flying at 300 m (985 ft) (as described in 6.5.2 of Annex 16, Volume I) at the propeller speed for maximum continuous power ($N_{MCP}$). Aeroplanes demonstrating compliance with Chapter 10 of Annex 16, Volume I should be flown according to 2.3 of Appendix 6 of Annex 16, Volume I. In this way, the aircraft overflies the microphone at the reference height ($H_{REF}$) (defined in 10.5.2. of Chapter 10 of Annex 16, Volume I), the best rate of climb speed ($V_y$) and at the propeller speed ($N_{MAX}$) corresponding to that defined in paragraph d) of the *Second phase* of 10.5.2 of Annex 16, Volume I. Noise measurements are repeated at two lower propeller speeds, typically 200 rpm and 400 rpm lower than $N_{MCP}$ or $N_{MAX}$. For Chapter 10 aeroplanes, these should be flown at speed $V_y$. The maximum A-weighted noise peak noise level ($LA_{max}$) is plotted against the propeller helical tip Mach number ($M_H$) in order to obtain the curve from which the source noise correction may be derived.

4.1.1.2 For fixed pitch propellers, it is generally not possible to separate the two significant noise generating parameters, helical tip Mach number and the power absorbed by the propeller, by using flight tests. A sensitivity curve of Mach number versus noise level derived from flight tests of a fixed pitch propeller (either level flyovers or fixed speed climbs) will therefore include within the curve the effects not only of the Mach number but also the power. Under these circumstances, it is not appropriate to apply a separate power correction.

### 4.1.2 Variable pitch propellers

4.1.2.1 For variable pitch propellers, the source noise sensitivity curves are developed from data taken with the aircraft flying over a range of propeller speeds (typically three) at a fixed torque or MAP in a manner similar to that described in 4.1.1 where $N_{MCP}$ or $N_{MAX}$ would, in this case, be the maximum propeller speed at the maximum permitted torque or MAP. This is repeated for two lower torque or MAP values in order to establish a carpet plot of maximum A-weighted noise levels against propeller speed and torque, MAP or shaft horsepower (SHP).

4.1.2.2 A plot of maximum A-weighted noise level ($LA_{max}$), helical tip Mach number ($M_H$) and torque or MAP is developed. This plot is then used to derive the source noise adjustment ($LA_{max}$) which is the difference between reference and test conditions at the noise certification power.

4.1.2.3 Generally the test and reference engine SHP can be derived from the engine manufacturer's performance curves. However, where such curves are not available, a correction should be applied to the manufacturer's published engine SHP (normally presented for a range of engine speeds under International Standard Atmosphere (ISA) and sea level conditions) in order to establish the engine power level under the test conditions of ambient temperature and air density. The correction is as follows:

For normally aspirated engines:

$$P_T = P_R\left[(T_R/T_T)^{1/2}\right][(\sigma - 0.117)/0.883] \;;$$

For turbo-charged engines:

$$P_T = P_R\left[(T_R/T_T)^{1/2}\right] \;,$$

where

$P_T$ and $P_R$ are the test and reference engine powers,

$T_T$ and $T_R$ are the test and reference ambient temperatures, and

$\sigma$ is the air density ratio.

*Note.— In this context, reference denotes the reference conditions for which the engine SHP is known.*

## 4.2 TAKE-OFF TEST AND REFERENCE PROCEDURES

*Note.— In planning a test programme for noise certification according to the provisions of Chapter 10 and Appendix 6 of Annex 16, Volume I, it is helpful to note the differences between test day flight procedures and the standardized take-off reference profile.*

4.2.1 The take-off reference profile is used to compute the altitude and speed of the aircraft passing over the microphone on a standard day. The requirements for this profile are contained in 10.5.2 of Chapter 10 in Annex 16, Volume I. They require that the first segment be computed by using airworthiness approved data, assuming take-off power is used from the brake release point to 15 m (50 ft) above the runway. The second segment is assumed to begin precisely at the end of the first segment, with the aeroplane in a climb configuration (gear up and climb flaps) and operating at the certificated speed for best rate of climb ($V_Y$). (See Figure 4-1.)

4.2.2 A worked example of the calculation of reference flyover height and reference conditions for correction of source noise for aeroplanes certificated according to the Standards of Chapter 10 in Annex 16, Volume I is presented in Appendix 5 of this manual.

4.2.3 The requirements for aeroplane test procedures are contained in two sections in Annex 16, Volume I, i.e. 10.6 of Chapter 10 and 2.3 of Appendix 6. They basically only refer to test tolerances and approval of test plans by certificating authorities.

4.2.4 Figure 4-1 illustrates the difference between the test and reference procedures. Note that the actual flight test path need not include a complete take-off from a standing condition. Rather, it assumes that a flight path intercept technique is used. As with the turbojet and helicopter standards, the aeroplanes would be flown to intersect the second phase (segment) climb path at the right speed and angle of climb when going over the microphone within 20 per cent of the reference height.

## 4.3 INSTALLATION OF ADD-ON SILENCERS (MUFFLERS)

4.3.1 Installation of an add-on silencer (muffler) may be an effective method for reducing the noise levels of a propeller-driven aeroplane powered by a reciprocating engine. However, an add-on silencer (muffler) may also degrade the performance of the aeroplane and therefore adversely affect the aircraft's noise characteristics.

4.3.2 The aeroplane performance characteristics must be re-evaluated after the installation of the add-on silencer (muffler). The type design change represented by the silencer (muffler) installation can be accepted as a no-acoustical change (NAC) (see 1.4.3) for compliance with Chapters 6 or 10 of Annex 16, Volume I, if the following conditions are verified to the satisfaction of the certificating authority:

a) for aircraft certificated according to Chapter 6 of Annex 16, Volume I, the aeroplane's take-off and climb performance, as determined by the performance correction defined in 4.2.3 of Appendix 3 of Annex 16, Volume I, is not adversely affected; or

b) for aircraft certificated according to Chapter 10 of Annex 16, Volume I, the aeroplane's take-off and climb performance, as determined by the reference height calculated in accordance with 10.5 of Chapter 10 of Annex 16, Volume I, is not adversely affected.

In either case, the add-on silencer (muffler) has no significant effect on the engine performance (power and rotational speed).

## 4.4 GUIDANCE ON THE USE OF A WINDSCREEN

4.4.1 For noise certification tests conducted according to Chapter 10 of Annex 16, Volume I, the microphone shall be installed in accordance with 4.4.1 of Appendix 6, which describes how the microphone shall be mounted in an inverted position so that the microphone diaphragm is 7 mm above and parallel to a circular metal plate. With this configuration, many certificating authorities have approved the use of a windscreen in order to minimize wind- and turbulence-induced pseudo sound levels and to protect the microphone during the test. A windscreen prepared and used in the manner described in 4.4.2 will cause no significant effect on the test result.

4.4.2 The windscreen must be made from a commercially available spherical foam windscreen cut into a hemispherical shape in order to accommodate the microphone over the plate. In preparing the hemispherical windscreen, the following points shall be ensured:

a) the cut surface of the windscreen must not be damaged by the cutting process; and

b) with the microphone properly inserted into the hemispherical windscreen and mounted over the ground plate, the microphone diaphragm must be at the specified distance from the plate's surface.

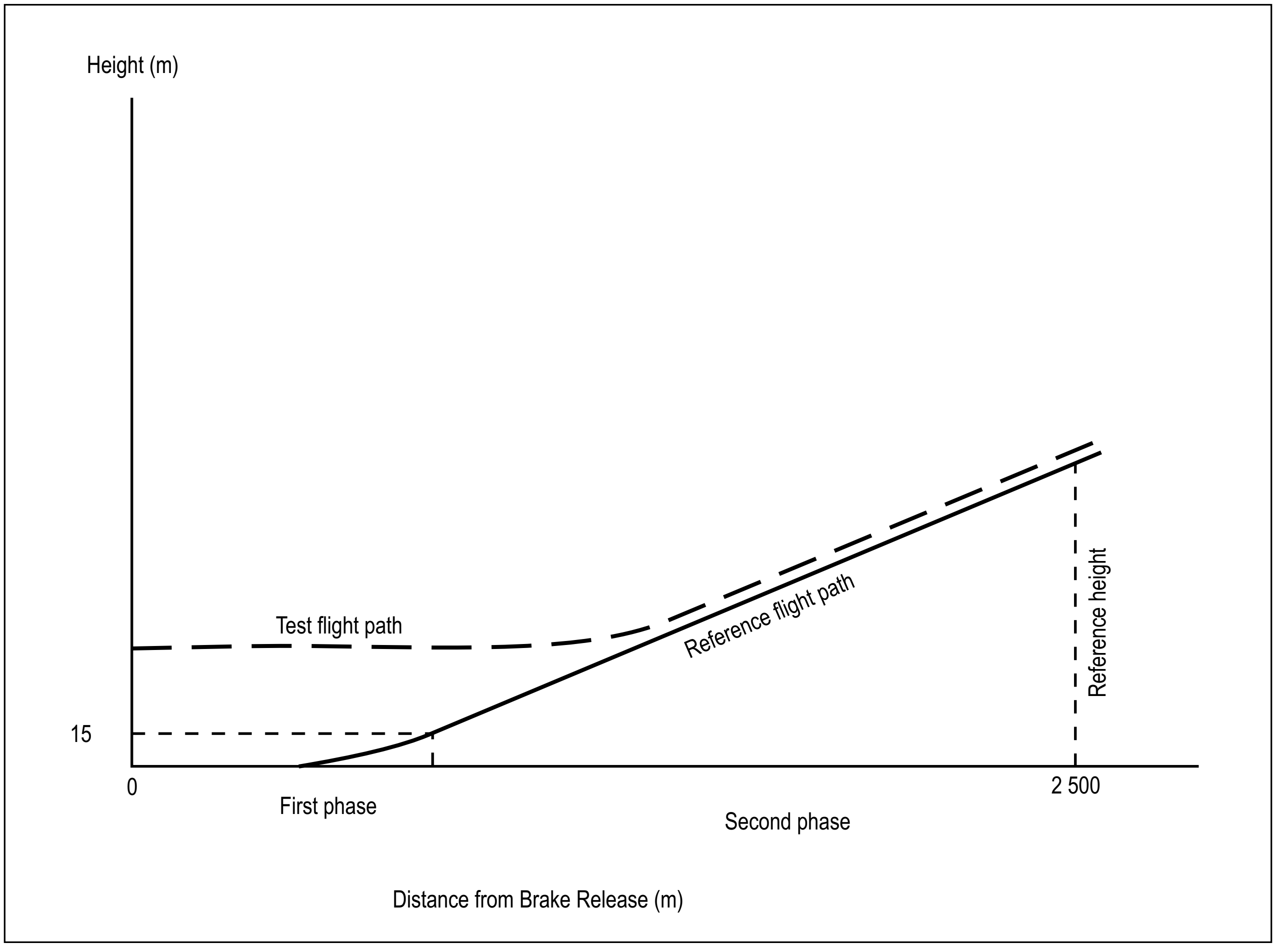


**Figure 4-1. Typical test and reference procedures**

# Chapter 5

# EQUIVALENT PROCEDURES FOR HELICOPTERS — FLIGHT TEST PROCEDURES

The objective of a noise certification demonstration test is to acquire data for establishing an accurate and reliable definition of a helicopter's noise characteristics (see 8.7 of Annex 16 — *Environmental Protection*, Volume I — *Aircraft Noise*). In addition, Annex 16, Volume I establishes a range of test conditions and procedures for adjusting measured data to reference conditions.

## 5.1 FLIGHT TEST PROCEDURES

### 5.1.1 Noise certification guidance

The following paragraphs are designed to clarify the requirements as set out in Chapter 8 and Appendix 2 of Annex 16, Volume I.

5.1.1.1 *Helicopter test window for zero adjustment for atmospheric attenuation*

5.1.1.1.1 There is currently a "test window" contained in Annex 16, Volume I (see 2.2.2 of Appendix 2) which needs to be met before test results are acceptable to certificating authorities. In addition, if the test conditions fall within a "zero attenuation adjustment window" (see Figure 5-1), defined as the area enclosed by [*2°C, 95% RH; 30°C, 95%RH; 30°C, 35% RH; 15°C, 50% RH; and 2°C, 90% RH*], the atmospheric attenuation adjustment of the test data may be taken as zero. Accordingly, the terms $0.01[(i) - (i)_0]QK$ and $0.01(i)_0\ (QK - Q_rK_r)$ from the equation for $SPL\ (i)_r$ in 8.3.1 of Appendix 2 in Annex 16, Volume I, become zero and the adjusted equation for $SPL\ (i)_r$ adjustment becomes:

$$SPL(i)_r = SPL(i) + 20 \log (QK/Q_r\ K_r)$$

5.1.1.1.2 Furthermore, provided that all the measured points for a particular flight condition are:

— within the "zero attenuation adjustment window" as defined in Figure 5-1, and

— within the appropriate height tolerances of ±9 m (or ±30 ft) for flyover, ±10 m (or ±33 ft) for approach and the 2 EPNdB limit for the take-off height adjustment given in 8.7.4a) of Chapter 8 of Annex 16, Volume I,

then the ratios of the reference and test slant distances for the propagation path adjustments may be replaced by the ratios of the reference and test distances to the helicopter when the helicopter is over the centre noise measuring point.

5.1.1.1.3 The total effect of both simplifications cited in 5.1.1.1.1 and 5.1.1.1.2 is that the equation of 8.3.1 of Appendix 2 of Annex 16, Volume I becomes:

$$SPL(i)_r = SPL(i) + 20 \log (HK/H_r\ K_r)$$

and the duration adjustment term specified in 8.4.2 of Appendix 2 of Annex 16, Volume I becomes:

$$\Delta_2 = -7.5 \log (HK/H_r\ K_r) + 10 \log (V/V_r)$$

where

$HK$ is the measured distance from the helicopter to the noise measuring point when the helicopter is directly over the centre noise measuring point and $H_rK_r$ is the reference distance.

5.1.1.2 *Helicopter test speed*

5.1.1.2.1 There are two requirements on helicopter test speeds. Firstly, the airspeed during the 10 dB-down time period should be close to the reference speed, i.e. within 9 km/h (5 kt) (see 8.7.6 of Annex 16, Volume I) to minimize speed adjustments for the three certification conditions of take-off, flyover and approach.

5.1.1.2.2 The second speed requirement applies to the flyover case (see 8.7.7 of Annex 16, Volume I). The number of level overflights made with a headwind component shall be equal to the number of overflights made with a tailwind component. The objective is to minimize the effect of wind on the measured flyover noise levels. For practical reasons, if the absolute wind speed component in the direction of flight, as measured at a height of 10 m (33 ft) above ground, is less than 9 km/h (5 kt), then the effect of wind can be considered to be negligible. In this case, the measured overflight may be used to satisfy a pass in either direction if the number of overflights in one direction is equal to the number in the opposite direction.

5.1.1.2.3 The applicant may find that although there are at least three valid overflights with a headwind component and three valid overflights with a tailwind component, there are more valid overflights with one wind component than with another. In this case, the applicant will need to discuss with the certificating authority which overflights are to be used in the determination of the final Effective Perceived Noise Level (EPNL) value for overflight. In many cases, preference may be given to using level overflights performed in pairs in order that the meteorological conditions are as far as possible identical for the two overflights in each pair. Hence, there is merit in considering conducting overflights in pairs for all wind speed conditions. Each pair should consist of two overflights performed one after the other in opposite directions over the reference flight track.

5.1.1.2.4 The measurement of ground-speed may be obtained by timing the helicopter as it passes over two points at a known distance apart on the helicopter track during the overflight noise measurements. These two points should straddle the noise measurement microphone array.

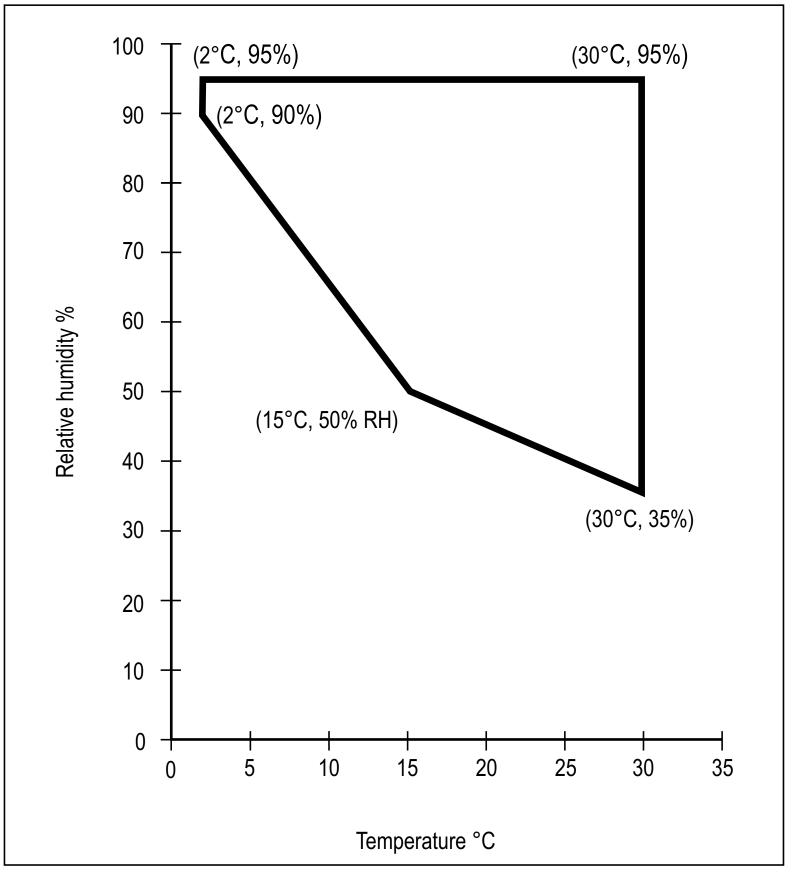


**Figure 5-1. Annex 16, Volume I, Chapter 8 "zero attenuation adjustment window"**

5.1.1.3 *Test speed for light helicopters*

5.1.1.3.1 For the purposes of compliance with Chapter 11 of Annex 16, Volume I, the helicopter should be flown at test speed ($V_{AR}$) which will produce the same advancing blade Mach number ($M_R$) as the reference speed in reference conditions given in 11.5.1.4 and 11.5.2.1 b) of Chapter 11 of Annex 16, Volume I.

5.1.1.3.2 The reference advancing blade Mach number ($M_R$) is defined as the ratio of the arithmetic sum of the main rotor blade tip rotational speed ($V_{TIP}$) and the helicopter true airspeed ($V_{REF}$) divided by the speed of sound ($c$) at 25°C (346.1 m/s) such that:

$$M_R = \frac{V_{TIP} + V_{REF}}{c} \quad .$$

The test airspeed ($V_{AR}$) is calculated from:

$$V_{AR} = c_T \left( \frac{V_{TIP} + V_{REF}}{c} \right) - V_{TIP}$$

where:

$c_T$ is the speed of sound obtained from the on-board measurements of outside air temperature.

Since the ground speed obtained from the overflight tests will differ from that for reference conditions, an adjustment $\Delta_2$ of the form:

$$\Delta_2 = 10 \log (V_{AR} / V_{REF})$$

will need to be applied. $\Delta_2$ is the increment in decibels that must be added to the measured sound exposure level (*SEL*).

5.1.1.3.3 There are two additional requirements for light helicopter test speed. Firstly, the airspeed during the 10 dB-down time interval should be close [i.e. within 5 km/h (3 kt)] to the adjusted reference speed (see 11.6.7 of Chapter 11 and 2.4 of Appendix 4 of Annex 16, Volume I).

5.1.1.3.4 The second speed requirement states that the level overflights shall be made in equal numbers with a headwind component and tailwind component (see 11.6.4 of Chapter 11 of Annex 16, Volume I). For practical reasons, if the absolute wind speed component in the direction of flight, as measured at a height between 1.2 m (4 ft) and 10 m (33 ft) above ground (see 2.2.2 d) of Appendix 4 of Annex 16, Volume I), is less than 9 km/h (5 kt), then the effect of wind can be considered to be negligible. In this case, the measured overflight may be used to satisfy a pass in either the headwind or tailwind direction if the overflights are conducted in pairs. Each pair should consist of two overflights performed one after the other in opposite directions over the reference flight track.

5.1.1.4 *Helicopter test mass*

5.1.1.4.1 The mass of the helicopter during the noise certification demonstration (see 8.7.11 in Chapter 8 of Annex 16, Volume I) must lie within the range of 90 per cent to 105 per cent of the maximum take-off mass for the take-off and flyover and between 90 per cent to 105 per cent of the maximum landing mass for the approach demonstration. For noise certification purposes, the effect of change of mass is to change the test day flight path for take-off, and adjustments to the reference flight path should be made for spherical spreading and atmospheric attenuation as described in Section 8 of Appendix 2, Annex 16, Volume I.

5.1.1.4.2 In some cases, such as when the test aircraft weight is restricted to a value somewhat less than the anticipated final certification weight, the applicant may, subject to the approval of the certificating authority, apply specific corrections for weight variations. The applicant may be approved to use a 10-log relationship correction or otherwise determine, by flight test, the variation of EPNL with weight. In such a case, the weights tested should include the maximum allowable test weight.

*Note.— A similar correction procedure may be acceptable when the certificated weight is increased by a small amount subsequent to the flight tests.*

5.1.1.5 *Helicopter approach*

Paragraph 8.7.10 of Chapter 8 in Annex 16, Volume I constrains the approach demonstration to within ±0.5° of the reference approach angle of 6°. Adjustments to the reference approach angle are required to account for spherical spreading effects and atmospheric attenuation as described in Section 8 of Appendix 2, Annex 16, Volume I.

5.1.1.6 *Helicopter flight path tracking*

In 2.3 of Appendix 2 of Annex 16, Volume I, it requires that the helicopter position relative to the flight path reference point be determined and synchronized adequately with the noise data between the 10 dB-down points. The methods used include:

a) radar or microwave tracking system;

b) theodolite triangulation; and

c) photographic scaling.

These techniques may be used singly or in combination. Practical examples of aircraft tracking systems employing one or more of these techniques are described in subsequent sections. This material is not intended to be an exhaustive list and additional information will be included as more experience is acquired.

### 5.1.1.6.1 Radar or microwave tracking system

One example of a radar position tracking system is shown in Figure 5-2. It operates on a principle of the pulse radar with a radar interrogator (receiver/transmitter) located on the aircraft and a radar transponder (reference/station) positioned at each reference station. The elapsed time between the receiver/transmitter pulse and reception of the pulse returned from the reference station transponder is used as the basis for determining the range of each reference station. This range information, together with the known location of the reference stations, can be used to obtain a fix on the position of the aircraft in three dimensions. A pulse coding system is employed to minimize false returns caused by radar interference on reflected signals.

The system performs the following basic functions during noise certification:

a) continuously measures the distance between the helicopter and four fixed ground sites;

b) correlates these ranges with IRIG-B time code and height information, and outputs these data to a pulse code modulation (PCM) recorder;

c) converts the aircraft range and height information into *X*, *Y* and *Z* position coordinates in real time; and

d) uses the *X*, *Y* and *Z* data to drive a cockpit display providing the pilot with steering and position cueing.

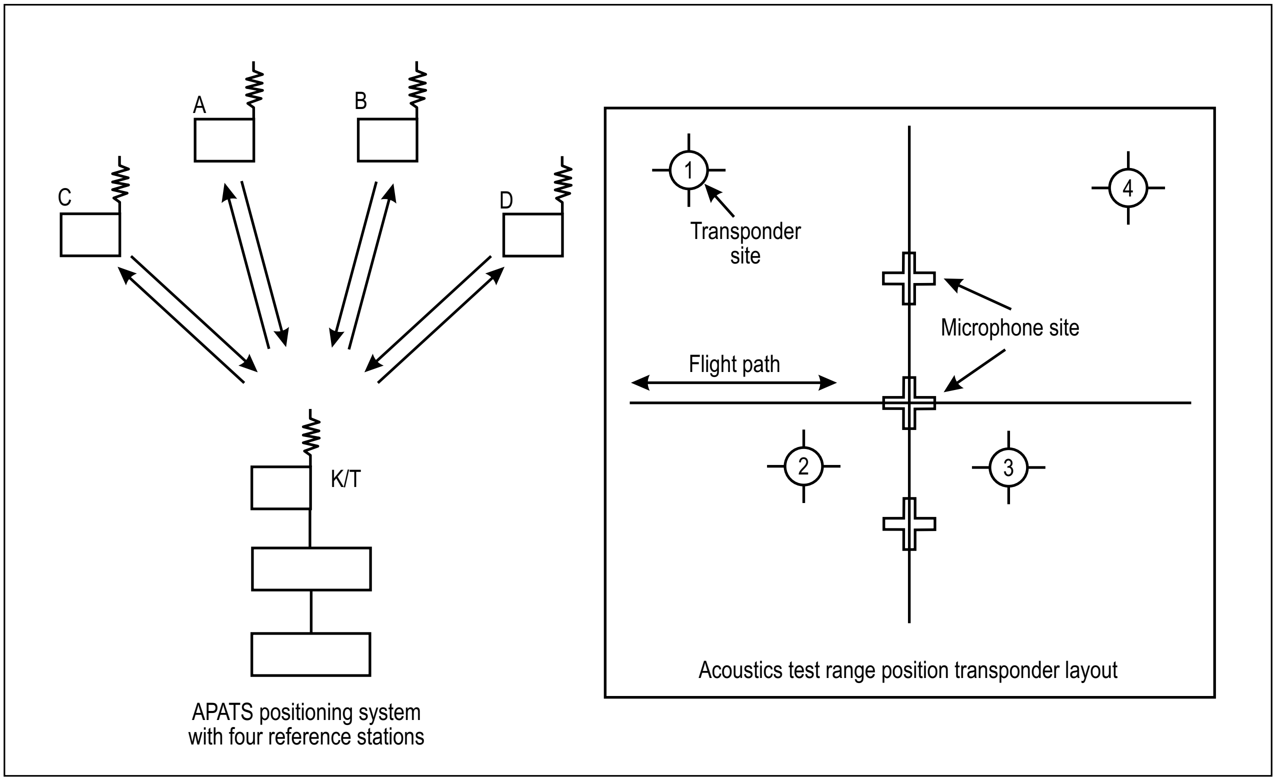


**Figure 5-2. Radar position tracking system**

The accuracy of the coordinate calculation depends on the flight path and transponder geometry. Errors are minimized when ranges intersect and the recommended practice is to keep the intersection angle near to 90°. The four transponder arrangements shown in Figure 5-2 produce position uncertainties from ±1.0 m to ±2.0 m.

At low aircraft heights some inaccuracies can be introduced with the use of microwave systems. The use of a radio-altimeter can reduce these errors. The height data are recorded, and synchronized with the microwave system.

*Helicopter equipment*. The distance measuring unit computer and transponder beacon are connected to a hemispherical antenna which is mounted under the fuselage, on the aircraft centreline, as close to the helicopter centre of gravity as possible.

*Ground equipment*. The four beacons are located on either side of the aircraft track to permit the optimum layout, i.e. covering the helicopter with angles between 30° and 150° (90° being the ideal angle).

For example, two beacons can be located in the axis of the noise measurement points at ±500 m of the central microphone, while another two beacons can be located under track at ±600 m from the central microphone.

### 5.1.1.6.2 Kinetheodolite system

It is possible to obtain helicopter position data with classical kinetheodolites, but it is also possible to make use of a system composed of two simplified theodolites, including a motorized photo-camera on a moving platform, which reports azimuth and elevation. These parameters are synchronized with coded time and the identification number of every photograph recorded.

Each 0.1 second, azimuth and elevation data are sent to a central computer which calculates the helicopter position $X$, $Y$ and $Z$ versus time for each trajectory.

Photography stations are located at sideline positions, about 300 m from the track, and at 200 m on either side of the three noise measurement points.

The accuracy of such a system can be ±1.5 m in ($X$, $Y$ and $Z$) over the working area.

### 5.1.1.6.3 Radar/theodolite triangulation

The opto-electronic system shown diagrammatically in Figure 5-3 uses a single optical theodolite to provide azimuth and elevation while range data are obtained from

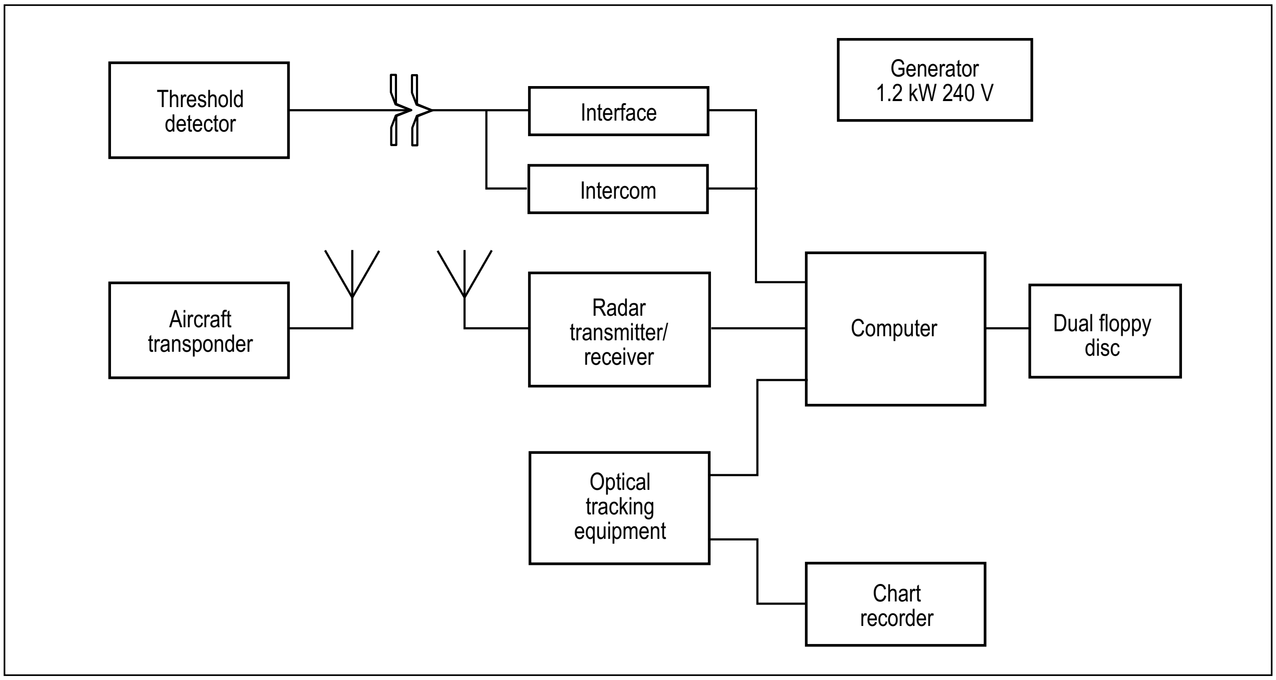


**Figure 5-3. Radar/optical position tracking system**

a radar tracking system using a single transponder. Data from these two sources are transferred to a desktop calculator at a rate of 20 samples/second from which three-dimensional position fixes can be derived. The system also provides tape start and stop times to the measuring sites, synchronizing all tape recording times. The accuracy of the system is approximately ±2.0 m, ±1.0 m and ±2.0 m for horizontal range ($X$), cross-track ($Y$) and height ($Z$) respectively. Uncertainties associated with determination of the visual glide slope indicator and ground speed are ±0.1° and ±0.5 kt.

#### 5.1.1.6.4 Photographic scaling

The flight path of the helicopter during the noise certification demonstration may be determined by using a combination of ground based cameras and height data supplied as a function of time from the on-board radio or pressure altimeters.

With this method, three cameras are placed along the intended track, such that one is sited close to the centre microphone position and the other two sited close to each of the 10 dB-down points (typically 500 m on either side of the microphone), depending upon the flight procedure being used. The cameras are mounted vertically and are calibrated so that the image size, obtained as the helicopter passes overhead, can be used to determine the height of the aircraft. It is important that the time at which each camera fires is synchronized with the on-board data acquisition system so that the height of the aircraft as it passes over each of the cameras can be correlated with the heights obtained from the photographs.

The flight path of the helicopter as a function of distance may be obtained by fitting the aircraft data to the camera heights.

The aircraft reference dimension should be as large as possible in order to maximize the photograph image size but it should also be chosen and used with care if errors in aircraft position are to be avoided. Foreshortening of the image due to main rotor coning (bending of the blades), disc tilt or fuselage pitch attitude, if not accounted for, will result in overestimates of height, lateral and longitudinal offsets.

By erecting a line above each of the cameras at right angles to the intended track, at a sufficient height above the camera in order to provide a clear photographic image of both the line and the helicopter, the applicant may obtain the lateral offset of the helicopter as it passes over each of the cameras. This can be done by attaching marks to the line showing the angular distances from overhead at 5° intervals on either side of the vertical.

This method may be used to confirm that the helicopter follows a 6° ± 0.5° glide slope within 10° of the overhead of the centre microphone as required by 8.7.8 and 8.7.10 of Chapter 8 of Annex 16, Volume I.

Furthermore, from the synchronized times of the helicopter passing over the three camera positions, the ground speed can be determined for later use in the duration correction adjustment.

Overall accuracy of the system is ±1.0 per cent of height and ±1.3 per cent of longitudinal and lateral displacements. Mean approach/climb angles and mean ground speed can be determined within ±0.25° and ±0.7 per cent, respectively.

### 5.1.1.7 *Atmospheric test conditions*

The temperature, relative humidity and wind velocity limitations are contained in 2.2.2 of Appendix 2 of Annex 16, Volume I. The parameters are measured at 10 m (33 ft). For adjustment purposes, the measured values of these parameters are assumed to be representative of the air mass between the helicopter and the microphones. No calculation procedures based on the division of the atmosphere into layers are required, but such a method of analysis could be accepted by the certificating authority.

### 5.1.1.8 *Procedure for the determination of source noise correction*

5.1.1.8.1 For demonstration of overflight reference noise certification levels, off-reference adjustments shall normally be made by using a sensitivity curve of Maximum Tone Corrected Perceived Noise Level (PNLTM) versus advancing blade tip Mach number deduced from flyovers carried out at different airspeeds around the reference airspeed; however, adjustment may be made by using an alternative parameter or parameters approved by the certificating authority. If the test aircraft is unable to attain the reference value of advancing blade tip Mach number or the agreed reference noise correlating parameter, then an extrapolation of the sensitivity curve is permitted, provided that the data cover a range of values of the noise correlating parameter between test and reference conditions as agreed by the certificating authority. The advancing blade tip Mach number or agreed noise correlating parameter shall be computed from as-measured data using true airspeed, on-board outside air temperature (OAT) and rotor speed. A separate curve of source noise versus advancing blade tip Mach number or another agreed noise correlating parameter shall be derived for each of the three certification microphone locations, i.e. centreline, sideline left and sideline right. Sidelines left and right are defined relative to the direction of the flight on each run. PNLTM adjustments are to be applied to each microphone datum using the appropriate PNLTM function.

5.1.1.8.2 In order to eliminate the need for a separate source noise correction to the overflight test results, the following test procedure is considered acceptable when the correlating parameter is the main rotor advancing blade tip Mach number ($M_R$). Each overflight noise test must be conducted such that:

a) the adjusted reference true airspeed ($V_{AR}$) is the reference airspeed ($V_R$) specified in 8.6.3 of Chapter 8 of Annex 16, Volume I, adjusted as necessary to produce the same main rotor advancing blade tip Mach number as associated with reference conditions;

*Note 1.— The reference advancing blade tip Mach number (*$\mathrm{M_R}$*) is defined as the ratio of the arithmetic sum of the main rotor blade tip rotational speed (*$\mathrm{V_{TIP}}$*) and the helicopter reference speed (*$\mathrm{V_R}$*) divided by the speed of sound (*c*) at 25°C (346.1 m/s) such that:*

$$M_R = \frac{V_{TIP} + V_{REF}}{c},$$

*and the adjusted reference true airspeed (*$V_{AR}$*) is calculated from:*

$$V_{AR} = c_T\left(\frac{V_{TIP} + V_{REF}}{c}\right) - V_{TIP} \quad ,$$

*where*

$c_T$ *is the speed of sound from the on-board measurement of outside static air temperature (see 6.7 of this manual).*

b) the test true airspeed ($V$) shall not vary from the adjusted reference true airspeed ($V_{AR}$) by more than ±5 km/h (±3 kt) or an equivalent approved variation from the reference main rotor advancing blade tip Mach number;

c) in practice, the tests will be flown to an indicated airspeed which is the adjusted reference true airspeed ($V_{AR}$) corrected for compressibility effects and instrument position errors; and

d) the on-board outside static air temperature must be measured at the overflight height just prior to each flyover.

*Note 2.— The calculation of noise levels, including the corrections, is the same as that described in Chapter 8 and Appendix 2 of Annex 16, Volume I, except that the need for source noise adjustment is eliminated. It should be emphasized that in the determination of the duration correction (*$\Delta 2$*), the speed adjustment to the duration correction is calculated as 10 log* (Vg/Vgr), *where* Vg *is the test ground speed and* Vgr *is the reference ground speed.*

### 5.1.2 On-board flight data acquisition

5.1.2.1 It is necessary to obtain the values of a variety of flight and engine parameters during the noise measurement period in order to:

a) determine the acceptability of helicopter noise certification flight tests;

b) obtain data to adjust noise data; and

c) synchronize flight, engine and noise data.

Typical parameters would include airspeed, height/altitude, rotor speed, torque, time etc.

5.1.2.2 A number of methods for collecting this information have been employed:

a) manual recording;

b) magnetic tape recording;

c) automatic still photographic recording;

d) cine recording; and

e) video recording.

5.1.2.3 Clearly, when a large number of parameters have to be collected at relatively short time intervals, it may not be practicable to manually record the data. Thus the use of one of the automatic systems listed in 5.1.2.2 b) to e) of this manual becomes more appropriate. The choice of a particular system may be influenced by a number of factors, such as the space available, cost, availability of equipment etc.

5.1.2.4 For systems which optically record the flight deck instruments (5.1.2.2 c) to e)), care must be taken to avoid strong lighting contrast (such as would be caused by sunlight and deep shadow), and reflections from the glass fronts of instruments which would make data unreadable. To avoid this, it may be necessary to provide additional lighting to "fill in" the deep shadow regions. To prevent reflections from the front of instruments, it is recommended that light coloured equipment or clothing on the flight deck be avoided. Flight crews should be required to wear black or dark coloured clothing and gloves.

5.1.2.5 Furthermore, for systems which record the readings of dials, it is important that the recording device is as near as possible directly in front of the instruments to avoid parallax errors.

5.1.2.6 *Magnetic tape recording*

Multi-channel instrumentation tape recorders designed for airborne environments are employed for continuous recording of flight and engine performance parameters. Typical recorders are compact intermediate/wide band and can take both ½-inch and 1-inch magnetic tapes with a 24 to 28 volt DC power requirements. Six tape speeds as well as both direct and FM recording are available in a tape recorder weighing about 27 kg.

5.1.2.7 *Automatic still photographic recording*

Photographs of the flight deck instrument panel can be taken by using a hand-held 35 mm single-lens reflex (SLR) camera with an 85 mm lens and high speed slide film. The indications on the instruments can be read by projecting the slides onto a screen.

5.1.2.8 *Cine recording*

Cine cameras with a one frame per second exposure rate have been used to acquire flight deck data. Care must be taken in mounting the camera to ensure that all the instruments that have to be photographed are within the field of view. Typical film cassettes containing about 2 000 frames have been used with a frame counter to allow film changes to be anticipated.

5.1.2.9 *Video recording*

Flight and engine performance parameters can be recorded with a video camera, although as with cine cameras, care must be taken to ensure that all the instruments that have to be photographed are within the field of view. The recorded information is played back using freeze-frame features to obtain individual instrument readings.

5.1.2.10 *Time synchronization of recorded data*

The need to synchronize the noise recordings with the on-board recorded flight deck data is important. This will involve radio communication between the helicopter and the noise recording positions. Several methods have been used, such as noting the synchronization time on a clock mounted on the instrument panel which itself is recorded by the data acquisition system. One such system uses a ground camera which operates a radio transmission which, when received by the helicopter, lights two high-intensity light emitting diodes (LEDs) that are mounted in an analogue clock attached to the instrument panel.

### 5.1.3 Procedures for the determination of changes in noise levels

Noise level changes determined by comparison of flight test data for different helicopter model series have been used to establish certification noise levels of modified or newly derived versions by reference to the noise levels of the baseline or "flight datum" helicopter model. These noise changes are added to or subtracted from the noise levels obtained from individual flights of the "flight datum" helicopter model. The confidence intervals of the new data are statistically combined with the "flight datum" data to develop overall confidence intervals (see Appendix 1 of this manual).

5.1.3.1 *Modifications or upgrades involving aerodynamic drag changes*

The use of drag devices, such as drag plates mounted beneath or on the sides of the "flight datum" helicopter, has proven to be effective in the noise certification of modifications or upgrades involving aerodynamic drag changes. External modifications of this type are made by manufacturers and aircraft "modifiers". Considerable cost savings are realized by not having to perform noise testing of numerous individual modifications to the same model series.

Based on these findings, it is considered acceptable to use the following as an equivalent procedure:

a) for helicopters to be certificated under Chapter 8 or Chapter 11 of Annex 16, Volume I, a drag device is used that produces the aerodynamic drag calculated for the highest drag modification or combination of modifications;

b) with the drag-producing device installed, a flyover test and take-off and/or approach test, if considered appropriate by the certificating authority (as in the case of a Chapter 8 certification) or a flyover test (as in the case of a Chapter 11 certification) are performed by using the appropriate noise certification reference and test procedures;

c) a relationship of noise level versus change in aerodynamic drag or airspeed is developed by using noise data (adjusted as specified in Appendix 2 or Appendix 4 of Annex 16, Volume I) of the "flight datum" helicopter and of the "high drag" configuration;

d) the actual airspeed of the modification to be certificated is determined from performance flight testing of the baseline helicopter with the modification installed; and

e) using the measured airspeed of the modification, certification noise levels are determined by interpolation of the relationship developed in item c).

### 5.1.4 Temperature and relative humidity measurements

5.1.4.1 Temperature and relative humidity measurements, as defined in 2.2.3 of Appendix 2, Annex 16, Volume I, have to be made at a height of 10 m (33 ft) above the ground. The measured values are used in the adjustment of the measured one-third octave band sound pressure levels to account for the difference in the sound attenuation coefficients in the test and reference atmospheric conditions as given in 8.3.1 of Appendix 2 in Annex 16, Volume I. The distances $QK$ and $Q_rK_r$ in the equations of 8.3.1 refer to the distances between positions on the measured and reference flight paths corresponding to the apparent PNLTM position and the noise measurement point.

5.1.4.2 As a consequence, the procedure assumes that the difference between the temperature and relative humidity at 10 m (33 ft) and the PNLTM position is zero or small and that the atmosphere can be represented by the values measured at 10 m (33 ft) above the ground in the vicinity of the noise measurement point. Data obtained from European and U.S. certification tests over a number of years and records provided by the U.K. Meteorological Office have confirmed that this assumption is valid over a wide range of meteorological conditions.

5.1.4.3 Noise certification measurements made under test conditions where significant changes in temperature and/or relative humidity with height are expected, particularly when a significant drop in humidity with altitude is expected, should be adjusted by using the average of the temperature and relative humidity measured at 10 m (33 ft) above the ground and at the height associated with the PNLTM point in order to eliminate errors associated with the use of data measured at 10 m (33 ft) only. Such special conditions might be encountered in desert areas shortly after sunrise, where the temperature near the ground is lower and the relative humidity considerable higher, than at the height associated with the PNLTM point. Except for tests made under such conditions, experience from noise certification tests over many years clearly indicates that the calculations of 8.3.1 of Appendix 2 of Annex 16, Volume I can be based on meteorological data measured at 10 m (33 ft) only.

5.1.4.4 Paragraph 2.2.2 of Appendix 2 in Annex 16, Volume I limits testing to conditions where the sound attenuation rate in the 8 kHz one-third octave band is not more than 12 dB/100 m. If, however, the dew point and dry bulb temperature are measured with a device which is accurate to within ±0.5°C, it has been found acceptable by certificating authorities to permit testing in conditions where the 8 kHz sound attenuation rate is not more than 14 dB/100 m.

#### 5.1.4.5 *Testing of light helicopters outside Chapter 11 temperature and humidity limits*

With the approval of the certificating authority, it may be possible to conduct testing of light helicopters outside the test environment specified in 2.2 of Appendix 4 in Annex 16, Volume I, provided the test environment is within the temperature and relative humidity limits specified in 2.2 of Appendix 2 in Annex 16, Volume I. In such circumstances, it will be necessary to conduct a one-third octave band analysis of a noise recording of each overflight. The measured value of sound exposure level (SEL) shall be corrected from the test values of temperature and relative humidity measured according to 2.2.2 of Appendix 4 in Annex 16, Volume I to the reference conditions defined in 11.5.1.4 of Chapter 11 in Annex 16, Volume I. The correction procedure shall be similar to that defined in 8.3.1 of Appendix 2 in Annex 16, Volume I, with the propagation distances $QK$ and $Q_rK_r$ replaced by $H$, the height of the test helicopter when it passes over the noise measurement point and by $H_R$, the reference height, 150 m, respectively.

### 5.1.5 Anomalous test conditions

5.1.5.1 Paragraph 2.2.2.f) of Appendix 2 in Annex 16, Volume I requires that the tests be conducted under conditions where no anomalous meteorological conditions exist. The presence of anomalous atmospheric conditions can be determined to a sufficient level of certainty by monitoring the outside air temperature (OAT) with the use of the aircraft instruments. Anomalous conditions which could impact the measured levels can be expected to exist when the OAT at 150 m (492 ft) is 2°C (3.6°F) or more than the temperature measured at 10 m (33 ft) above ground level. This check can be made in level flight at a height of 150 m (492 ft) within 30 minutes of each noise measurement.

5.1.5.2 Since the actual heights associated with the PNLTM points will not be known until the analysis is made, measurements of temperature and relative humidity can be made at a number of heights and the actual value determined from a chart of temperature and relative humidity versus height. Alternatively, since the influence of height is small, measurements at a fixed height in the order of 120 m (or 400 ft) and 150 m (or 500 ft) can be used, depending on the flight condition and agreed with the certificating authority prior to the tests being conducted.

5.1.5.3 If tests are adjusted by using the “average” of the temperature and relative humidity measured at 10 m (33 ft) and the height association with the PNLTM point as described in 5.1.4.4 of this manual, the provisions of 5.1.5.1 do not apply. The reason is that the impact of any anomalous meteorological conditions are taken into account by using the average of the temperature and relative humidity at 10 m (33 ft) and the height associated with the PNLTM point.

# Chapter 6

# EVALUATION METHODS

## 6.1 INTRODUCTION

Several methods used to resolve difficulties encountered during the measurement and analysis of aircraft noise data have been developed. Some of these procedures are applicable to all aircraft types, whereas others have limited application to one or more aircraft types. This chapter presents these evaluation methods and describes specific procedures which have been approved to deal with:

a) spectral irregularities which are not related to the aircraft noise sources;

b) background noise levels, both acoustic and electrical;

c) the establishment and extension of databases;

d) the use of inertial navigation systems for aeroplane flight path measurements;

e) the integrated analysis of noise data;

f) the computation of Effective Perceived Noise Level (EPNL) by the integrated method of adjustment; and

g) the calculation of the speed of sound.

## 6.2 SPECTRAL IRREGULARITIES

Tone corrections are required for tones or irregularities in the spectra of aeroplane noise. Irregularities which occur in measured spectra due to interference effects caused by the reflection of sound from the ground surface or by perturbations during the propagation of the noise from the aeroplane to the microphone need to be identified so that tone corrections are not applied to spectral characteristics which are not related to the aeroplane noise source. As specified in 4.3.1 of Appendix 2 of Annex 16 — *Environmental Protection*, Volume I — *Aircraft Noise*, narrow band analysis is one recommended procedure for identifying these false tones. Other methods of identification that have been approved for use in certification are included in Appendix 2 of this manual. The effect of these spectral irregularities however are not normally removed from the data of propeller-driven aeroplanes or helicopters since they are difficult to differentiate from engine and propeller or rotor associated tones.

## 6.3 BACKGROUND NOISE LEVELS

Background noise levels, including background acoustic noise levels and electronic noise from measuring and analysis equipment, can mask noise levels from aeroplanes over parts of the frequency range of interest for EPNL calculations. The effects of background noise may be removed by using an approved procedure such as described in Appendix 3 of this manual.

## 6.4 ESTABLISHMENT AND EXTENSION OF DATABASES

6.4.1 Noise certification levels may be determined from a number of repeat noise measurements (at least six) taken at the same engine thrust (power or, for helicopters, transmitted power), height, speed and configuration at each of the reference noise measurement positions. The noise measurements are adjusted to reference conditions and the mean value, while the 90 per cent confidence interval is obtained in accordance with 5.4.2 of Appendix 2 of Annex 16, Volume I. As an alternative, an aircraft may be flown over a range of noise correlating parameters ($\mu$). In the case of aeroplanes, the correlating parameter may be engine thrust (power) setting and/or helical tip Mach number for propeller-driven aeroplanes. For helicopters, the parameter may be the power setting, advancing blade tip Mach number, speed or any other agreed parameter. At least six flights are needed to establish the noise level versus the relevant correlating parameter relationship covering the range relevant to both the prototype and derived aircraft for each of the reference noise measurement sites. Provided that the 90 per cent confidence interval limit of not greater than ±1.5 EPNdB (or ±1.5 dBA, as appropriate) is satisfied, as calculated in Appendix 1 of this manual, the noise certification levels may be obtained by entering the curve of noise level versus correlating parameter ($\mu$) at the appropriate reference $\mu$.

6.4.2 In some areas an extrapolation of the data field may be approved but care must be taken to ensure that the relative contributions of the component noise sources to the effective perceived noise level, sound exposure level or A-weighted noise level, as appropriate, remains essentially unchanged and that a simple extrapolation of noise/correlating parameter curves can be made.

6.4.3 For propeller driven aeroplanes a change in propeller and/or powerplant may necessitate further flight tests to establish a revised noise-power-distance relationship.

## 6.5 TEST ENVIRONMENT CORRECTIONS

6.5.1 The atmospheric conditions specified in 2.2.2 b), c), d) and e) of Appendix 2 in Annex 16, Volume I require the measurement of ambient air temperature and relative humidity profiles during noise certification tests in order to ensure that the temperatures, relative humidities and corresponding atmospheric sound absorption coefficients do not deviate from the specified limits over the whole noise path between ground and aeroplane. Ordinarily, profile measurements are recorded by balloon, instrumented aeroplane or other similar method during flight testing in order to ensure that the criteria are met.

6.5.2 At the discretion of the certificating authority atmospheric profile, measurements of ambient air temperature and relative humidity may be made by instruments mounted on the test aeroplane and may be considered sufficient to determine compliance with the criteria specified in 2.2.2 b), c), d) and e) in Appendix 2 of Annex 16, Volume I.

## 6.6 INERTIAL NAVIGATION SYSTEMS FOR AEROPLANE FLIGHT PATH MEASUREMENT

6.6.1 The criteria for the measurement of aeroplane height and lateral position relative to the intended track are described in 2.3 of Appendix 2 in Annex 16, Volume I. This section indicates that the method used should be independent of normal flight instrumentation. Since the development of this requirement, other tracking systems (e.g. inertial navigation systems (INS) and microwave systems) which have a high degree of accuracy have been installed in aeroplanes and consequently have been accepted by several certificating authorities for use during noise certification. However, it is important that any inherent drift in the system is determined regularly and the system calibrated. For this purpose, ground-based cameras can be used to determine the position of an aeroplane relative to the cameras both laterally and in terms of height. The calibration should be undertaken sufficiently frequently to retain the accuracy specification of the system.

6.6.2 The accuracy of the tracking systems must be acceptable to the certificating authority.

## 6.7 COMPUTATION OF EPNL BY THE INTEGRATED METHOD OF ADJUSTMENT

6.7.1 Paragraph 9.1 of Appendix 2 in Annex 16, Volume I provides for the use of the "simplified" or "integrated" method for adjusting measured noise data to reference day conditions. The "integrated" procedure may be applied to measured data at the flyover, lateral, and approach noise measurement points. With the "integrated" adjustment method, all data adjustments are applied to each measured set of sound pressure levels obtained at 0.5-second intervals in order to identify equivalent reference average sound pressure levels which are used to compute EPNLs consistent with values which would be obtained under reference conditions. For complete acoustic consistency the adjustment is only applicable if evaluated for identical pairs of noise emission angle ($\theta$) relative to the flight path and for noise elevation angle ($\Psi$) relative to the ground for both the measured (test) and adjusted (reference) flight paths. While this requirement may be satisfactorily approximated for the flyover and approach noise measurements, it can be shown that it is not possible to retain identical pairs of angles when lateral noise measurement adjustments are necessary. Therefore when lateral noise measurement adjustments are made by the "integrated" method, the geometric conditions of identical noise emission angle should be maintained for test and reference flight paths while the corresponding differences between test and reference elevation angles should be minimized. The slight difference that will occur between test and reference elevation angle will have negligible effect on the corrected EPNL value.

6.7.2 This section describes an integrated adjustment method that is applicable for use when the aeroplane is operated at constant conditions (flight path and power) during the noise measurement period.

### 6.7.3 Test aircraft position

6.7.3.1 The "integrated" method for adjustment of measured noise level data to reference conditions requires acoustic and aeroplane performance data at each 0.5-second time interval during the test flights. These data include aeroplane position relative to a three-dimensional ($X$, $Y$ and $Z$) coordinate system, one-third-octave band sound pressure levels $SPL\ (i,\ k)$, and time ($t_k$) at the midpoint of each averaging time period relative to a reference time. Additionally, aeroplane performance parameters, the measurement microphone locations, and temperature and humidity are required for each flyover.

6.7.3.2 The aircraft height ($Z$) is measured above the reference $X$-$Y$ plane (generally taken to be the ground plane) with the measurement microphone 1.2 m above this reference plane. The average test flight path is assumed to be a straight line (except when thrust (power) reduction is used during the flyover measurement) and the time-correlated aeroplane-position data are used to determine the time of overhead ($t_{oh}$), the test overhead height ($h_{To}$)[1] and the test minimum distance ($d_{Tm}$) from the test flight path to the microphone location [$K\ (X_{TM},\ Y_{TM},\ Z_{TM})$].

6.7.3.3 Using the test data directly or by geometric analysis of the relation between the average straight line flight path and the minimum distance line from $K_T$ to $R_T$ ($X_{RT},\ Y_{RT},\ Z_{RT}$) as shown in Figure 6-1, the minimum distance becomes:

$$d_{Tm} = [(X_{RT} - X_{TM})^2 + (Y_{RT} - Y_{TM})^2 + (Z_{RT} - Z_{TM})^2]^{1/2} \quad (1)$$

### 6.7.4 Sound propagation times and sound emission angles

6.7.4.1 The test sound propagation time ($\Delta t_{pk}$) is identified with the data record time ($t_k$), the noise emission time ($t_{ek}$), the aeroplane position ($A_k$) at time ($t_{ak}$), and the averaging time ($t_{Av}$) through the relationships:

$$t_k = t_{ak} - {}^1\!/\!{}_2 t_{Av} \qquad (2)$$

$$t_{ek} = t_k - \Delta t_{pk} \qquad (3)$$

$$\Delta t_{pk} = K_T\, Q_{ek}/c_T \qquad (4)$$

where

$c_T$ is the speed of sound for the average absolute temperature of the air between the surface ($T_s$) and the height of the aeroplane ($T_A$) (see 6.8 of this manual, where $T = (T_s + T_A) / 2$).

6.7.4.2 Using the geometric relationships of Figure 6-2, the minimum distance derived from Equation (1), the test distance $Q_{ek}R$, and defining the time difference $B$ equal to $t_{Tm} - t_k$ yields the following expression for the test flight path sound propagation times:

$$\Delta t_{Tpk} = [1/(c_T^2 - V_T^2)]$$

$$\times \{BV_T^2 + [(c_T^2 - V_T^2)(d_{Tm})^2 + (Bc_TV_T)^2]^{1/2}\} \qquad (5)$$

where

$V_T$ is the average true airspeed of the test aeroplane along the flight path.

6.7.4.3 Similarly, the test sound emission angle is defined as:

$$\theta_{ek} = \sin^{-1}\,(d_{Tm}/d_{Tpk})\ ,$$

or

$$\theta_{ek} = \sin^{-1}\,[d_{Tm}/(\Delta t_{Tpk})(c_T)]\ . \qquad (6)$$

### 6.7.5 Aircraft reference flight path

6.7.5.1 The geometry of the reference flight path is essentially similar to that shown in Figure 6-1; however, the following differences exist.

a) The reference flight path is directly over the runway centreline (i.e. $Y_{DEV} = 0$).

b) For the take-off and approach flyovers, the measurement station is on the runway centreline (i.e. $Y_{rr} = Y_{rM}$).

c) For lateral noise measurements, ($Y_{rr} - Y_{rM}$) equals the reference lateral displacement of the measurement station.

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[1] For emphasis, the subscript "T" is used here for test conditions. Annex 16 uses unsubscripted symbols for test conditions.

*Note 1.— The subscript "r" is used to denote reference conditions.*

*Note 2.— The reference microphone location (*$K_r$*) for flyover or lateral noise measurements is usually at the same coordinates as for the test location (*$K_T$*), i.e. (*$X_{TM}$, $Y_{TM}$, $Z_{TM}$*) = (*$X_{rM}$, $Y_{rM}$, $Z_{rM}$*).*

6.7.5.2 The reference flight path may be geometrically specified relative to the reference microphone location ($K_r$) by using the measurement station lateral distance, the height overhead ($h_{ro}$) and the flight path inclination angle ($\gamma_r$). These values are equated to the minimum distance ($d_{rm}$) from $K_r$ by the following equations:

$$d_{rm} = [h_{ro}^2 \cos^2 \gamma_r + (Y_{Rr} - Y_{rM})^2]^{1/2} \qquad (7a)$$

or

$$d_{rm}\ [(X_{Rr} - X_{rM})^2 + (Y_{Rr} - Y_{rM})^2 + (Z_{Rr} - Z_{rM})^2]^{1/2} \qquad (7b)$$

6.7.5.3 The basic acoustic assumption relating the test and reference flight conditions is that the three dimensional acoustic emission angles ($\theta_{ek}$ and $\theta_{erk}$) for each test record time ($t_k$) and the corresponding reference time ($t_{rk}$) are equal. Using Equation (6) and this equality, the test sound pressure levels, $SPL_T\ (i,\ k)$, for each of the *i-th* frequency bands, are adjusted for spherical spreading and atmospheric absorption over the acoustic path lengths

a) by the equation:

$$SPL_r(i,\ rk) = SPL_T\,(i,\ k) - 20 \log\,(d_{rpk}/d_{Tpk})$$
$$- [(a_{i0})d_{rpk} - (a_i)d_{Tpi}] \qquad (8a)$$

where

$a_{i0}$ and $a_i$ are the reference and test day sound attenuation coefficients, respectively, or;

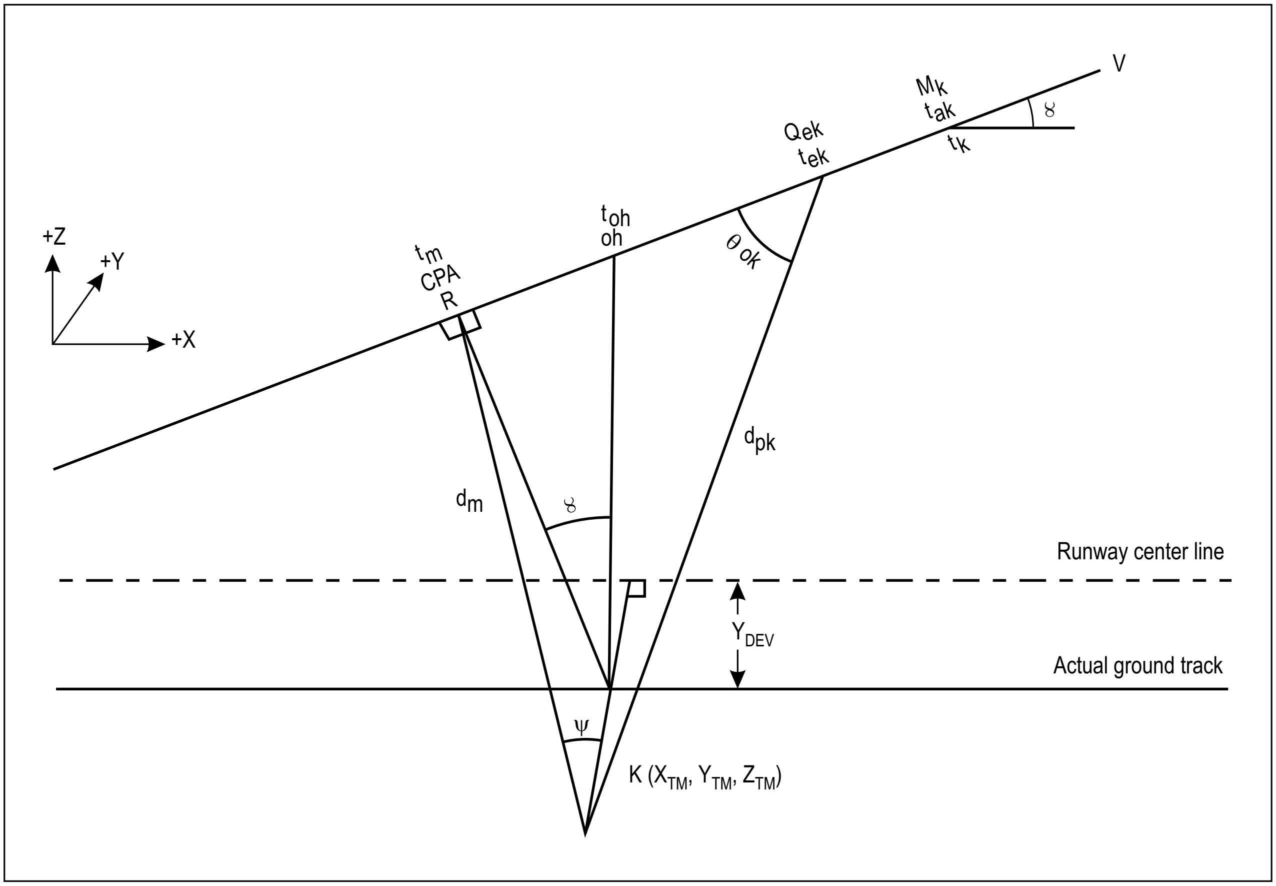

**Figure 6-1. Geometry for integrated procedure**

b) when the test and reference flight path minimum distances are used, by the equation:

$$SPL_r(i,\ rk) = SPL_T(i,\ k) - 20 \log (d_{rm}/d_{Tm}) - [(a_{i0})d_{rm} - (a_i)d_{Tm}] \operatorname{cosec} \theta_{ek}\ . \quad (8b)$$

### 6.7.6 Time interval computation

6.7.6.1 In addition to the above adjustments of the test data for spherical spreading and atmospheric absorption, it is necessary to make an adjustment for the change in the time increment $t_{rk}$, that is used in the computation of EPNL. Since the time increments are not equal to the 500 ms test measurement time increments when adjusted by the "integrated" method, successive aeroplane position reference times [$t_{rk}$ *and* $t_{r(k+1)}$] occur after the time reference ($t_{rek}$) at the sound emission point (Figure 6-2). The average time increment to be used in the EPNL computation is:

$$\delta t_{rk} = [\Delta t_{rk} + \Delta t_{r(k-1)}]/2 \quad (9)$$

where the reference time interval ($\Delta t_{rk}$) between data records is:

$$\Delta t_{rk} = t_{r(k+1)} - t_{rk}\ .$$

Using the relationship between sample times, sound emission times and sound propagation times, the reference interval becomes:

$$\Delta t_{rk} = [t_{re(k+1)} - t_{rek}] + [\Delta t_{rp(k+1)} - \Delta t_{rpk}]\ . \quad (10)$$

6.7.6.2 This time interval reflects the time for the aeroplane to travel at test and reference speeds ($V_T$ and $V_r$) from one sound emission point to the next, and also the effect of differences between test and reference minimum distances ($d_{rm}$ and $d_{Tm}$) as well as sound speeds ($c_r$ and $c_T$). These factors are expressed explicitly by arranging Equation (10) as follows:

$$\Delta t_{rk} = (d_{rm}/d_{Tm})\ \{(V_T/V_r)[0.5 - (\Delta t_{Tp(k+1)} - \Delta t_{Tpk})] + (c_T/c_r)\ (\Delta t_{Tp(k+1)} - \Delta t_{Tpk})\}\ . \quad (11)$$

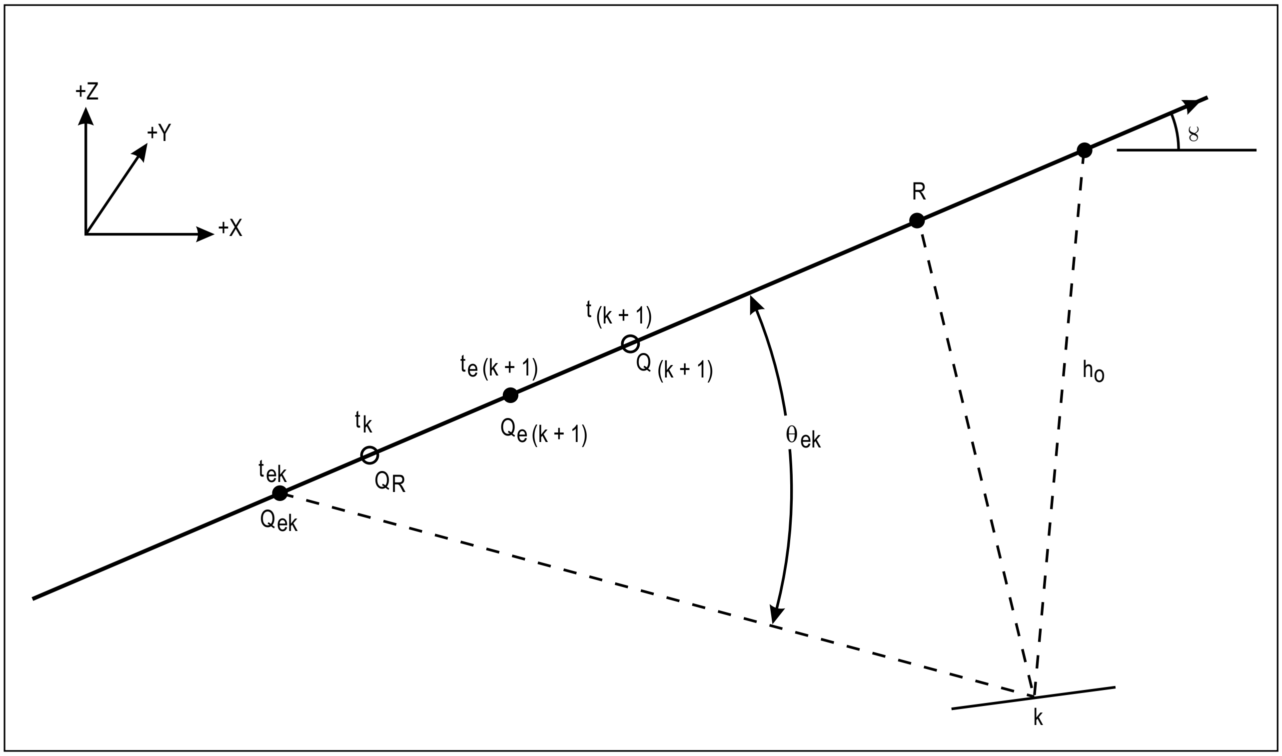

Figure 6-2. Relative time periods for integrated procedure

### 6.7.7 Adjusted EPNL

After the sound pressure levels have been adjusted by using Equation (8), the tone corrections are calculated according to 4.3 of Appendix 2 in Annex 16, Volume I. In addition, using the noy weighting and the procedure for calculating Perceived Noise Level (PNL) (see 4.2, Appendix 2 in Annex 16, Volume I), the reference Tone Corrected Perceived Noise Levels (PNLTs) are available for the times $t_{r1}$ to $t_{rn}$ which include the first and last 10 dB-down times. These values and the adjusted average time increment, Equation (9), are then combined to compute the adjusted EPNL as follows:

$$\mathrm{EPNL} = 10\log\left[\left(\frac{1}{T_0}\right)\sum_{k=1}^{n}(10^{0.1\mathrm{PNLT}_k})(\delta t_{rk})\right],$$

where the reference time ($T_0$) is 10 seconds and the summation is started by setting $\Delta t_{r\,(1-1)} = \Delta t_{r\,(2-1)}$ so that $\delta t_{r\,(1-1)} = \Delta t_{rl}$. The summation is terminated by assuming $\Delta t_{rn} = \Delta t_{r\,(n-1)}$ giving $\delta t_{rn} = \Delta t_{rn} = \Delta t_{r\,(n-1)}$.

## 6.8 CALCULATION OF THE SPEED OF SOUND

For the purposes of noise certification, the value of the speed of sound, $c$, shall be calculated from the equation taken from ISO 9613-1: 1993(E):

$$c = 343.2\ (T/T_0)^{½}\ \text{metres/second}$$

$$(\text{i.e. } c = 1\,125.9\ (T/T0)^{½}\ \text{feet/second})$$

where

$T_O$ = 293.15 K and

$T$ is the absolute ambient air temperature.

# Chapter 7

# MEASUREMENT AND ANALYSIS EQUIPMENT

In previous revisions of the *Environmental Technical Manual on the Use of Procedures in the Noise Certification of Aircraft* (Doc 9501, Second Edition), this chapter described “new” instrumentation standards which had been approved by CAEP to replace the then existing Section 3 of Appendix 2 of Annex 16 — *Environmental Protection*, Volume I — *Aircraft Noise*. With the publication of Amendment 7 of Annex 16, Volume I, these “new” instrumentation standards have henceforth been transferred to Annex 16, Volume I.

# Chapter 8

# CONTROL OF NOISE CERTIFICATION COMPUTER PROGRAM SOFTWARE AND DOCUMENTATION RELATED TO STATIC-TO-FLIGHT PROJECTION PROCESSES

## 8.1 GENERAL

8.1.1 Procedures for computer program software control shall be developed, approved by the certificating authority, and maintained and adhered to by each applicant utilizing "static-to-flight equivalencies (SFEs)".

8.1.2 The procedures shall consist of four key elements which, when implemented by the noise certification applicant, shall result in documentation which properly describes and validates the applicable SFE noise certification computer program and data output. Throughout the development of a given aeroplane type, adherence to these procedures will enable the tracking of critical computer programs in order to verify that the initial software design has not been changed without substantiation.

8.1.3 The four key elements of configuration index, software control plan, design description and verification process are described in 8.2.

## 8.2 SOFTWARE CONTROL PROCEDURES: FOUR KEY ELEMENTS

### 8.2.1 Configuration index

A configuration index shall be established for each unique SFE software system. It will include all applicable elements of the software system and provide historic tracking of documents and software under control. Where appropriate, the index may be maintained in a general database.

### 8.2.2 Software control plan

8.2.2.1 A procedure for SFE software change management shall be established that includes the baseline design identification, a software change control system and a method of reviewing and auditing software changes and maintaining a status accounting of changes.

8.2.2.2 Control of software changes shall be maintained by establishing baselines within the verification process (see 8.2.4) and by documenting modifications to the baseline case that result from program coding changes. Review and auditing procedures will be established within the verification process to allow the validity of the program coding changes for the "modified" configuration to be assessed relative to the "baseline" configuration.

8.2.2.3 The configuration index shall be updated to reflect, historically, the changes made to the software system.

### 8.2.3 Design description

A technical description of the methods used to accomplish the SFE certification shall be provided, including an overview and a description of the software system design to accomplish the technical requirements. The software design description should include the program structure, usage of subroutines, program flow control and data flow.

### 8.2.4 Verification process

The validation process for the SFE software system, or modifications to it, shall include a procedure to verify that the calculations described in the documentation are being performed properly by the software. The process may include manual calculations compared to computer output, stepwise graphical displays, software audits, diagnostic subroutines that generate output of all relevant variables associated with the modifications, or other methods to establish confidence in the integrity of the software. The process results shall be monitored and tracked relative to software calculation changes.

## 8.3 APPLICABILITY

Although the software control plan is applicable to all SFE-specific computer program software and documentation established through the specific procedures and processes of each applicant, it may not be necessary to review and audit ancillary software (such as, but not limited to, subroutines dealing with atmospheric absorption rates, noy calculations, tone corrections) for each main program source code change.

# Chapter 9

# GUIDELINES FOR NOISE CERTIFICATION OF TILT-ROTOR AIRCRAFT

Guidelines have been developed for the noise certification of tilt-rotor aircraft. These are presented as Attachment F to Annex 16 — *Environmental Protection*, Volume I — *Aircraft Noise*. To help in the understanding of these guidelines and to assist in their application, background information is presented in Appendix 7 of this manual.

# Chapter 10

# REFERENCES

1. Tester, B.J. and V.M. Szewczyk. *Jet Mixing Noise: Comparison of Measurement and Theory.* AIAA Paper 79-0570.

2. Laufer, J., R.E. Kaplan and W.T. Chu. *Noise Produced by Subsonic Jets.* 1974 Proceedings of the Second Inter-Agency Symposium on University Research in Transportation Noise, Volume 1, pp. 50-58.

3. Fink, M.R. *Airframe Noise Prediction Method.* Washington, DC: 29 March 1977. USA DOT Report FAA-RD-77-29.

4. SAE ARP 866A–1975. *Standard Values of Atmospheric Absorption as a Function of Temperature and Humidity.* N.p.: 1975.

5. SAE ARP 876D–1993. *Gas Turbine Jet Exhaust Noise Prediction*. N.p.: 1993.

6. SAE AIR 1672B–1983. *Practical Methods to Obtain Free Field Sound Pressure Levels from Acoustical Measurements over Ground Surfaces*. N.p.: 1983.

7. SAE AIR 1846–1984. *Measurement of Noise from Gas Turbine Engines During Static Operation*. N.p.: 1984.

8. SAE AIR 1905–1985: *Gas Turbine Co-axial Exhaust Flow Noise - Methods of Prediction Considered for Inclusion in SAE ARP 876*. N.p.: 1985.

9. ESDU Item 80038, Amendment A. *The Correction of Measured Noise Spectra for the Effects of Ground Reflection*. N.p.: n.d.

*Note 1.— ESDU Data items may be obtained from ESDU International Ltd., 251-259 Regent Street, London, W1R 7AD, United Kingdom.*

*Note 2.— SAE AIRs and ARPs may be obtained from the Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, PA 15096, United States of America.*

# Appendix 1

# CALCULATION OF CONFIDENCE INTERVALS

## 1. INTRODUCTION

1.1 The use of noise-power-distance (NPD) curves requires that confidence intervals be determined by using a more general formulation than is used for a cluster of data points. For this more general case, confidence intervals may have to be calculated about a regression line for:

a) flight test data,

b) a combination of flight test and static test data, and

c) analytical results, or

d) a combination thereof.

Items 1b) and 1c) are of particular significance for noise certifications of an aircraft model range and require special care when pooling the different sources of sampling variability.

1.2 Sections 2 to 5 of this appendix provide an insight into the theory of confidence interval evaluation. The application of this theory and some worked examples are presented in Section 6 of this appendix. A suggested bibliography is given in Section 7 for those wishing to gain a greater understanding.

## 2. CONFIDENCE INTERVAL FOR THE MEAN OF FLIGHT TEST DATA

### 2.1 Confidence interval for the sample estimate of the mean of clustered measurements

If $n$ measurements of Effective Perceived Noise Levels (EPNLs) are obtained under approximately the same conditions and it can be assumed that they constitute a random sample from a normal population with true population mean, μ, and true standard deviation, σ, then the following statistics can be derived:

$$\bar{y} = \text{estimate of the mean} = \frac{1}{n}\left\{\sum_{i=1}^{i=n} y(i)\right\},$$

$s$ = estimate of the standard deviation of the mean

$$= \sqrt{\frac{\sum_{i=1}^{i=n}(y_i - \bar{y})^2}{n-1}}.$$

From these and the Student's t-distribution, the confidence interval, $CI$, for the estimate of the mean, $y$, can be determined, as:

$$CI = \bar{y} \pm t_{\left(1-\frac{\alpha}{2},\, \xi\right)} \frac{s}{\sqrt{n}}$$

where $t_{(1-\alpha/2,\, \zeta)}$ denotes the $(1-\alpha/2)$ percentile of the single-sided Student's t-test with ζ degrees of freedom (for a clustered data set $\zeta = n - 1$) and where ζ is defined such that $100(1-\alpha)$ per cent is the desired confidence level for the confidence interval. In other words, it denotes the probability with which the interval will contain the unknown mean, μ. For noise certification purposes, 90 per cent confidence intervals are generally desired and thus, $t_{.95,\, \zeta}$ is used. (See Table A1-3 at the end of this appendix for a listing of values of $t_{.95,\, \zeta}$ for different values of ζ.)

### 2.2 Confidence interval for mean line obtained by regression

2.2.1 If $n$ measurements of EPNL $y_1, y_2, \ldots\ldots, y_n$ are obtained under significantly varying values of engine-related parameter $x_1, x_2, \ldots\ldots, x_n$, respectively, then a polynomial can be fitted to the data by the method of least squares. The following polynomial regression model for the mean EPNL, $\mu$, is assumed to apply:

$$\mu = B_0 + B_1 x + B_2 x^2 + \ldots\ldots + B_k x^k$$

and the estimate of the mean line through the data of the EPNL is given by:

$$y = b_0 + b_1x + b_2x^2 + \ldots + b_kx^k .$$

2.2.2 Each regression coefficient $B_i$ is estimated by $b_i$ from the sample data using the method of least squares in a process summarized as follows.

2.2.3 Each observation ($x_i$, $y_i$) satisfies the equations

$$\begin{aligned} y_i &= B_0 + B_1x_i + B_2x_i^2 + \ldots + B_kx_i^k + \varepsilon_i \\ &= b_0 + b_1x_i + b_2x_i^2 + \ldots + b_kx_i^k + e_i \end{aligned}$$

where $\varepsilon_i$ and $e_i$ are the random error and residual, respectively, associated with the EPNL. The random error, $\varepsilon_i$, is assumed to be a random sample from a normal population with mean zero and standard deviation $\sigma$. The residual, $e_i$, is the difference between the measured value and the estimate of the value using the estimates of the regression coefficients and $x_i$. Its root mean square value, $s$, is the sample estimate for $\sigma$. These equations are often referred to as the normal equations.

2.2.4 The $n$ data points of measurements ($x_i$, $y_i$) are processed as follows:

Each elemental vector, $\underline{x}_i$ and its transpose $\underline{x}'_i$, are formed such that

$\underline{x}_i = (1\ x_i\ x_i^2\ \ldots\ldots\ x_i^k)$, a row vector, and

$$\underline{x}_i = \begin{pmatrix} 1 \\ x_i \\ x_i^2 \\ \cdot \\ \cdot \\ x_i^k \end{pmatrix}, \text{ a column vector.}$$

A matrix $\underline{X}$ is formed from all the elemental vectors $\underline{x_i}$ for $i = 1, \ldots, n$.

$\underline{X}'$ is the transpose of $\underline{X}$.

2.2.5 We define the matrix $\underline{A}$ such that $\underline{A} = \underline{X}'\ \underline{X}$ and $\underline{A}^{-1}$ is the inverse of $\underline{A}$.

2.2.6 In addition, $\underline{y} = (y_1\ y_2\ \ldots\ y_n)$, and, $\underline{b} = (b_0\ b_1\ \ldots\ b_k)$, with $\underline{b}$ determined as the solution of the normal equations:

$$\underline{y} = \underline{Xb}$$

and

$$\underline{X}'\ \underline{y} = \underline{X}'\underline{Xb} = \underline{Ab}$$

to give

$$\underline{b} = \underline{A}^{-1}\ \underline{X}'\ \underline{y}.$$

2.2.7 The 90 per cent confidence interval, $CI_{90}$, for the mean value of the EPNL estimated with the associated value of the engine-related parameter, $x_0$, is then defined as

$$CI_{90} = \overline{y}\,(x_0) \pm t_{.95,\,\zeta}\ s\ v(x_0) ,$$

where $v\,(x_0) = \sqrt{\underline{x}_0\underline{A}^{-1}\underline{x}'_0}$ .

2.2.8 Thus, $CI_{90} = \overline{y}\,(x_0) \pm t_{.95,\,\zeta}\ s\sqrt{\underline{x}_0\underline{A}^{-1}\underline{x}'_0}$ ,

where $\underline{x}_0 = \left[1\ x_0\ x_0^2\ \ldots\ x_0^k\right]$ ,

$\underline{x}'_0$ is the transpose of $\underline{x}_0$,

$\overline{y}\,(x_0)$ is the estimate of the mean value of the EPNL at the associated value of the engine-related parameter,

$t_{.95,\,\zeta}$ is obtained for $\zeta$ degrees of freedom. (For the general case of a multiple regression analysis involving $K$ independent variables (i.e. $K + 1$ coefficients), $\zeta$ is defined as $\zeta = n - K - 1$. For the specific case of a polynomial regression analysis, for which $k$ is the order of curve fit, we have $k$ variables independent of the dependent variable, and so $\zeta = n - k - 1$.) and

$$s = \sqrt{\frac{\sum_{i=1}^{i=n} [y_i - \overline{y}(x_i)]^2}{n-k-1}}$$ , the estimate of $\sigma$, the true standard deviation.

## 3. CONFIDENCE INTERVAL FOR STATIC TEST DERIVED NPD CURVES

3.3.1 When static test data are used in family certifications, NPD curves are formed by the linear combination of baseline flight regressions, baseline projected static regressions, and derivative projected static regressions in the form:

$$EPNL_{DF} = EPNL_{BF} - EPNL_{BS} + EPNL_{DS}$$

or using the notation adopted above:

$$\overline{y}_{DF}\,(x_0) = \overline{y}_{BF}\,(x_0) - \overline{y}_{BS}\,(x_0) + \overline{y}_{DS}\,(x_0)$$

where:

subscript *DF* denotes derivative flight,

subscript *BF* denotes baseline flight,

subscript *BS* denotes baseline static, and

subscript *DS* denotes derivative static.

3.3.2 Confidence intervals for the derivative flight NPD curves are obtained by pooling the three data sets, each with their own polynomial regression. The confidence interval for the mean derived EPNL at engine-related parameter $x_0$, i.e. for $\mu_{DF}(x_0)$, is given by:

$$CI_{90}(x_0) = \bar{y}_{DF}(x_0) \pm t' \, V_{DF}(x_0)$$

where $V_{DF}(x_0) =$

$$\sqrt{[s_{BF} v_{BF}(x_0)]^2 + [s_{BS} \; v_{BS}(x_0)]^2 + [s_{DS} \; v_{DS}(x_0)]^2}$$

with $S_{BF}$, $S_{BS}$, $S_{DS}$, $v_{BF}(x_0)$, $v_{BS}(x_0)$ and $v_{DS}(x_0)$ computed as explained in 2.2 of this appendix for the respective data sets indicated by the subscripts *BF*, *BS*, and *DS*, and

$t' =$

$$\frac{[s_{BF} v_{BF}(x_0)]^2 t_{BF} + [s_{BS} v_{BS}(x_0)]^2 t_{BS} + [s_{DS} v_{DS}(x_0)]^2 t_{DS}}{[s_{BF} v_{BF}(x_0)]^2 + [s_{BS} v_{BS}(x_0)]^2 + [s_{DS} v_{DS}(x_0)]^2}$$

where $t_{BF}$, $t_{BS}$ and $t_{DS}$ are the $t_{.95,\,\xi}$ values, each evaluated with the respective degrees of freedom $\xi_{BF}$, $\xi_{BS}$ and $\xi_{DS}$ as they arise in the corresponding regressions.

## 4. CONFIDENCE INTERVAL FOR ANALYTICALLY DERIVED NPD CURVES

Analysis may be used to determine the effect of changes in noise source components on certificated levels. This is accomplished by analytically determining the effect of hardware change on the noise component it generates. The resultant delta ($\Delta$) is applied to the original configuration and new noise levels are computed. The changes may occur on the baseline configuration or on subsequent derivative configurations. The confidence intervals for this case are computed using the appropriate method from Sections 2 and 3 of this appendix. If $\widehat{\Delta}$ represents the analytically determined change and if it is assumed that it may deviate from the true unknown $\Delta$ by some random amount $d$, i.e.

$$\widehat{\Delta} = \Delta + d \text{ ,}$$

where $d$ is assumed to be normally distributed with mean zero and known variance $\tau^2$, then the confidence interval for $\mu(x_0) + \Delta$ is given by:

$$[\bar{y}(x_0) + \hat{\Delta}] \pm t' v'(x_0) \text{ ,}$$

where $v'(x_0) = \sqrt{v(x_0)^2 + \tau^2}$ and $t'$ is as above without change.

## 5. ADEQUACY OF THE MODEL

### 5.1 Choice of engine-related parameter

Every effort should be made to determine the most appropriate engine-related parameter $x$, which may be a combination of various simpler parameters.

### 5.2 Choice of regression model

5.2.1 It is not recommended in any case that polynomials of greater complexity than a simple quadratic model be used for certification purposes, unless there is a clear basis for using a higher order polynomial.

5.2.2 Standard texts on multiple regression should be consulted and the data available should be examined to show the adequacy of the model chosen.

## 6. WORKED EXAMPLE OF THE DETERMINATION OF 90 PER CENT CONFIDENCE INTERVALS FROM THE POOLING OF THREE DATA SETS

### 6.1 Introduction

6.1.1 This section presents an example of the derivation of the 90 per cent confidence intervals arising from the pooling of three data sets. Worked examples and guidance material are presented for the calculation of confidence intervals for a clustered data set and for first order (i.e. straight line) and second order (i.e. quadratic) regression curves. In addition, this section also shows how the confidence interval shall be established for the pooling together of several data sets.

6.1.2 Consider the theoretical evaluation of the certification noise levels for an aircraft retrofitted with silenced engines. The approach noise level for the "flight datum" aircraft was derived from a clustered data set of noise levels measured at nominally reference conditions, to which were added source noise corrections derived from a quadratic least squares curve fit through a series of data points made at different engine thrusts. In order to evaluate the noise levels for the aircraft fitted with acoustically treated engines, a further source noise curve (assumed to be a straight least squares regression line) was established from a series of measurements of the silenced aircraft. Each of the three databases is assumed to be made up of data unique to each base.

6.1.3 The clustered data set consists of six EPNL levels for the nominal datum hardwall condition. These levels have been derived from measurements which have been fully corrected to the hardwall approach reference condition.

6.1.4 The two curves which determine the acoustic changes are the regression curves (in the example given in 6.1.2, both a quadratic and straight line least squares fit curves) for the plots of EPNL against normalized thrust for the hardwall and silenced conditions. These are presented in Figure A1-1 where the dotted lines plotted about each line represent the boundaries of the 90 per cent confidence interval.

6.1.5 Each of the two curves is made up from the full set of data points obtained for each condition during a series of back-to-back tests. The least squares fits therefore have associated with them all the uncertainties contained within each data set. It is considered that the number of data points in each of the three sets is large enough to constitute a statistical sample.

## 6.2 Confidence interval for a clustered data set

6.2.1 The confidence interval of the clustered data set is defined as follows:

Let $EPNL_i$ be the individual values of EPNL

$n$ = number of data points

$t$ = Student's t-distribution for $(n-1)$ degrees of freedom (the number of degrees of freedom associated with a clustered data set).

Then the confidence interval $CI = \overline{EPNL} \pm t\frac{s}{\sqrt{n}}$

where $s$, the estimate of the standard deviation, is defined as

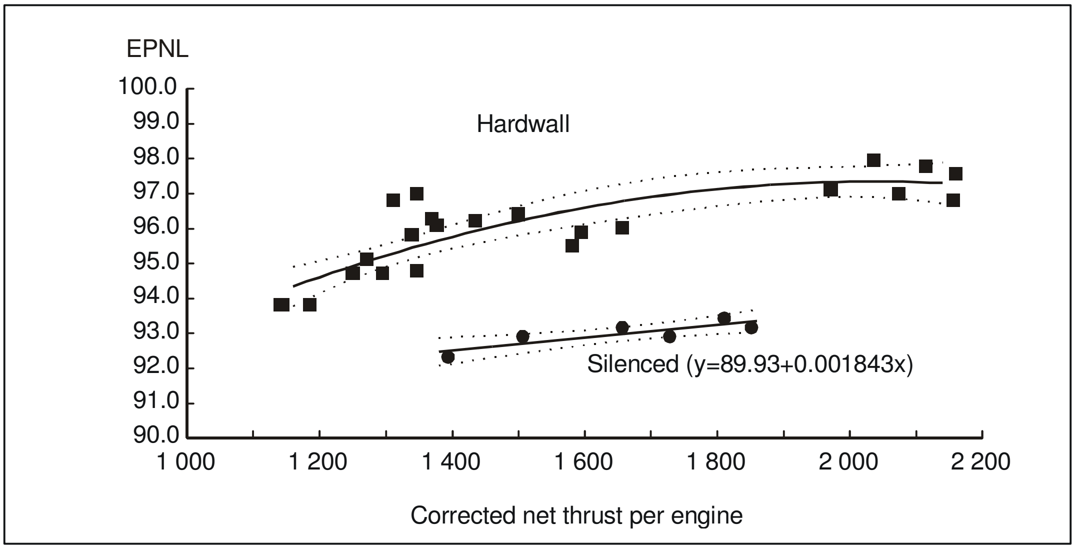

**Figure A1-1. Regression curves for the plots of EPNL against normalized thrust for the hardball and silenced conditions**

$$s = \sqrt{\frac{\sum_{i=1}^{i=n}(EPNL_i - \overline{EPNL})^2}{n-1}}$$

and $$\overline{EPNL} = \frac{\sum_{i=1}^{i=n} EPNL_i}{n} .$$

6.2.2 Let us suppose that our clustered set of EPNL values consists of the following:

| *Run Number* | *EPNL* |
|---|---|
| 1 | 95.8 |
| 2 | 94.8 |
| 3 | 95.7 |
| 4 | 95.1 |
| 5 | 95.6 |
| 6 | 95.3 |

Then the number of data points ($n$) = 6,

degrees of freedom ($n - 1$) = 5,

Student's t-distribution for 5 degrees of freedom = 2.015 (See Table A1-3),

$$\overline{EPNL} = \frac{\sum_{i=1}^{i=n} EPNL_i}{n} = 95.38 ,$$

$$s = \sqrt{\frac{\sum_{i=1}^{i=n}(EPNL_i - \overline{EPNL})^2}{n-1}} = 0.3869 ,$$

and the confidence interval ($CI$)

$$\begin{aligned} CI &= \overline{EPNL} \pm t\frac{s}{\sqrt{n}} \\ &= 95.38 \pm 2.015\,\frac{0.3869}{\sqrt{6}} = 95.38 \pm 0.318 . \end{aligned}$$

## 6.3 Confidence interval for a first order regression curve

6.3.1 Let us suppose that the regression curve for one of the source noise data sets (for the silenced case) can best be represented by a least squares straight line fit, i.e. a first order polynomial.

6.3.2 The equation for this regression line is of the general form:

$$Y = a + bX$$

where

$Y$ represents the dependent variable *EPNL*, and

$X$ represents the independent variable normalized thrust $F_N/\delta$ (in this case).

6.3.3 Although for higher order polynomial least squares curves, a regression line's coefficients (i.e. the solutions to the "normal equations") are best established through computer matrix solutions, the two coefficients for a straight line fit, *a* and *b*, can be determined from the following two simple formulas for the measured values of $X$ and $Y$, $X_i$ and $Y_i$:

$$b = \frac{Covariance}{Variance} = \frac{S_{xy}{}^2}{S_x{}^2}$$

where

$$S_{xy^2} = \frac{\sum_{i=1}^{i=n} X_i Y_i}{n} - \frac{\sum_{i=1}^{i=n} X_i \sum_{i=1}^{i=n} Y_i}{n^2}$$

and

$$S_{x^2} = \frac{\sum_{i=1}^{i=n} X_i^2}{n} - \left(\frac{\sum_{i=1}^{i=n} X_i}{n}\right)^2 ,$$

$$a = \frac{\sum_{i=1}^{i=n} Y_i - \sum_{i=1}^{i=n} X_i}{n} .$$

6.3.4 The 90 per cent confidence interval for this regression line for $X = x_0$ is then defined by:

$$CI_{90} = \bar{Y} \pm ts\sqrt{\underline{x_0}\underline{A}^{-1}\underline{x_0}'}$$

where

$t$ = Student's t-distribution for 90 per cent confidence corresponding to $(n - k - 1)$ degrees of freedom (where $k$ is the order of the polynomial regression line and $n$ is the number of data points),

$\underline{x_0} = (1 \quad x_0)$ and

$$\underline{x_0}' = \begin{pmatrix} 1 \\ x_0 \end{pmatrix},$$

$\underline{A}^{-1}$ is the inverse of $\underline{A} = \underline{X}'\,\underline{X}$,

with $\underline{X}$ and $\underline{X}'$ defined as in 2.2 of this appendix from the elemental vectors formed from the measured values of the independent variable $X_i$,

$$s = \sqrt{\frac{\sum_{i=1}^{i=n} (\Delta Y)_i^2}{n - k - 1}}$$

where $(\Delta Y)_i$ = the difference between the measured value of $Y_i$ at its associated value of $X_i$, and the value of $Y$ derived from the least squares fit straight line for $X = X_i$, and $n$ and $k$ are defined as the number of data points and the order of the polynomial regression line, respectively.

6.3.5 Let us suppose that our data set consists of the following set of six EPNL values (see Table A1-1), together with their associated values of engine-related parameter. (Note that it would be usual to have more than six data points making up a source noise curve but in order to limit the size of the matrices in this example, the number of data points has been restricted.)

6.3.6 By plotting this data (see Figure A1-1) it can be seen by examination that a linear relationship between EPNL (the dependent variable $Y$) and $F_N/\delta$ (the independent variable $X$) is suggested with the following general form:

$$Y = a + bX.$$

**Table A1-1. Values of sample data set**

| *Run Number* | $\frac{F_N}{\delta}$ | *EPNL* |
|---|---|---|
| 1 | 1 395 | 92.3 |
| 2 | 1 505 | 92.9 |
| 3 | 1 655 | 93.2 |
| 4 | 1 730 | 92.9 |
| 5 | 1 810 | 93.4 |
| 6 | 1 850 | 93.2 |

6.3.7 The coefficients $a$ and $b$ of the linear equation are defined as above and may be calculated as follows:

| $X$ | $Y$ | $XY$ | $X^2$ |
|---|---|---|---|
| 1 395 | 92.3 | 128 759 | 1 946 025 |
| 1 505 | 92.9 | 139 815 | 2 265 025 |
| 1 655 | 93.2 | 154 246 | 2 739 025 |
| 1 730 | 92.9 | 160 717 | 2 992 900 |
| 1 810 | 93.4 | 169 054 | 3 276 100 |
| 1 850 | 93.2 | 172 420 | 3 422 500 |
| $\Sigma_X$ | $\Sigma_Y$ | $\Sigma_{XY}$ | $\Sigma_x{}^2$ |
| 9 945 | 557.9 | 925 010 | 16 641 575 |

$$b = \frac{Covariance}{Variance} = \frac{S_{xy}{}^2}{S_x{}^2}$$

where

$$S_{xy}{}^2 = \frac{\sum_{i=1}^{i=n} X_i Y_i}{n} - \frac{\sum_{i=1}^{i=n} X_i \sum_{i=1}^{i=n} Y_i}{n^2}$$

$$= \frac{925\,010}{6} - \frac{(9\,945)(557.9)}{36} = 48.46$$

and

$$S_x{}^2 = \frac{\sum_{i=1}^{i=n} X_i^2}{n} - \left(\frac{\sum_{i=1}^{i=n} X_i}{n}\right)^2$$

$$= \frac{16\,641\,575}{6} - \left(\frac{9\,945}{3}\right)^2 = 26\,289.6$$

to give $b = \dfrac{48.46}{26\,289.6} = 0.001843$

and

$$a = \frac{\sum_{i-1}^{i=n} Y_i - b \sum_{i=1}^{i=n} X_i}{n}$$

$$= \frac{557.9 - (0.001843)(9\,945)}{6} = 89.93\ .$$

6.3.8 The 90 per cent confidence interval about this regression line which is defined as:

$$CI_{90} = \bar{Y} \pm ts\sqrt{\underline{x_0}\underline{A}^{-1}\underline{x_0}'}$$

is calculated as follows.

6.3.9 From the single set of measured independent variables tabulated in Table A1-1, let us form the matrix, *X*, from the elemental row vectors, such that:

$$\underline{X} = \begin{bmatrix} 1 & 1\,395 \\ 1 & 1\,505 \\ 1 & 1\,655 \\ 1 & 1\,730 \\ 1 & 1\,810 \\ 1 & 1\,850 \end{bmatrix}$$

and

$\underline{X}'$, the transpose of $\underline{X}$,

where

$$X' = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 1\,395 & 1\,505 & 1\,655 & 1730 & 1\,810 & 1\,850 \end{bmatrix}.$$

6.3.10 We now form the matrix $\underline{A}$, defined such that $\underline{A}, = \underline{X}'\ \underline{X}$ and so

$$\underline{A} = \begin{bmatrix} 6 & 9\,945 \\ 9\,945 & 16\,641\,575 \end{bmatrix}$$

and its inverse $\underline{A}^{-1}$such that

$$\underline{A}^{-1} = \begin{bmatrix} 17.5836 & -0.01051 \\ -0.01051 & 6.339E-6 \end{bmatrix}.$$

*Note.— The manipulation of matrices, their multiplication and inversion are best performed by computers through standard routines. Such routines are possible by using standard functions contained in many commonly used spreadsheets.*

6.3.11 Suppose we now wish to find the 90 per cent confidence interval about the regression line for a value of $F_N/\delta$ (i.e. $x_0$) of 1 600. We form the row vector $\underline{x_0}$ such that:

$$\underline{x_0} = \begin{bmatrix} 1 & 1\,600 \end{bmatrix}$$

and its transpose, a column vector:

$$\underline{x_0}' = \begin{bmatrix} 1 \\ 1\,600 \end{bmatrix}.$$

6.3.12 From our calculation of $\underline{A}^{-1}$, we have:

$$\underline{x_0}\underline{A}^{-1} = \begin{bmatrix} 1 & 1\,600 \end{bmatrix} \begin{bmatrix} 17.5836 & -0.01051 \\ -0.01051 & 6.3396\,E-6 \end{bmatrix}$$

$$= (0.7709 - 3.6453\,E-4)$$

and so

$$\underline{x_0}\underline{A}^{-1}x_0 = (0.7709 - 3.6453\,E-4)\begin{bmatrix} 1 \\ 1\,600 \end{bmatrix} = 0.1876\ .$$

6.3.13 Our equation for confidence interval also requires that we evaluate the value of standard deviation for the measured data set. From Table A1-1 and our regression equation for the least squares best fit straight line (from which we calculate the predicted value of EPNL at each of the six measured values of $F_N/\delta$), we proceed as follows:

| *Run Number* | $\dfrac{F_N}{\delta}$ | *EPNL (Measured)* | *EPNL (Predicted)* | $(\Delta EPNL)^2$ |
|---|---|---|---|---|
| 1 | 1 395 | 92.3 | 92.50 | 0.03979 |
| 2 | 1 505 | 92.9 | 92.70 | 0.03911 |
| 3 | 1 655 | 93.2 | 92.98 | 0.04896 |
| 4 | 1 730 | 92.9 | 93.12 | 0.04708 |
| 5 | 1 810 | 93.4 | 93.26 | 0.01838 |
| 6 | 1 850 | 93.2 | 93.34 | 0.01909 |

$$s = \sqrt{\frac{\sum_{i=1}^{i=n} (\Delta y)_i^2}{n-k-1}} = \sqrt{\frac{0.21241}{6-1-1}} = 0.2304$$

for $n = 6$ and $k = 1$.

6.3.14 Taking the value of Student's t distribution from Table A1-3 for $(n - k - 1)$ degrees of freedom (i.e. 4) to be 2.132, we have the confidence interval about the regression line at $F_N/\delta = 1\,600$ defined as follows:

$$\begin{aligned} CI_{90} &= \overline{EPNL} \pm ts\sqrt{\underline{x_0}\underline{A}^{-1}\underline{x_0}'} \\ &= 92.98 \pm (2.132)(0.2304)\sqrt{0.1876} \\ &= 92.98 \pm 0.2128\ . \end{aligned}$$

6.3.15 In order to establish the lines of 90 per cent confidence intervals about a regression line the values of $CI_{90}$ for a range of values of independent variable(s) should be calculated, through which a line can be drawn. These lines are shown as the dotted lines on Figure A1-1.

### 6.4 Confidence interval for a second order regression curve

The confidence intervals for a second order regression curve are derived in a similar manner to those for a straight line detailed in 6.2 of this appendix. A detailed example of their calculation is not discussed here. However the following points should be borne in mind.

6.4.1 The coefficients of the least squares regression quadratic line are best determined via computer matrix solutions. Regression analysis functions are a common feature of many proprietary software packages.

6.4.2 The matrices $\underline{x_0}, \underline{x_0}'$, $\underline{X}$ and $\underline{X}'$ formed during the computation of the confidence interval according to the formula:

$$CI_{90} = \bar{Y} \pm ts\sqrt{\underline{x_0}\underline{A}^{-1}\underline{x_0}'}$$

are formed from *1 x 3* and *3 x 1* row and column vectors, respectively, made up from the values of independent variable *X* according to the following general form:

$$x = (1\ x\ x^2) \text{ and } \underline{x}' = \begin{pmatrix} 1 \\ x \\ x^2 \end{pmatrix}\ .$$

6.4.3 The number of degrees of freedom associated with a multiple regression analysis involving *K* variables independent of the dependent variable (i.e. with $(K + 1)$ coefficients, including the constant term) is defined as $(n - K - 1)$. For a second order regression curve, we have two independent variables and so the number of degrees of freedom is $(n - 1)$.

### 6.5 Confidence interval for the pooled data set

The confidence interval associated with the pooling of three data sets is defined as follows:

$$CI = \bar{Y} \pm T\sqrt{\sum_{i=1}^{i=3} Z_i^2}$$

where

$$Z_i = \frac{CI_i}{t_i}$$

with $CI_i$ = confidence interval for the *i'th* data set,

$t_i$ = value of Student's *t* distribution for the *i'th* data set,

and

$$T = \frac{\sum_{i=1}^{i=3} Z_i^2 t_i}{\sum_{i=1}^{i=3} Z_i^2}\ .$$

The different stages in the calculation of the confidence interval at our reference thrust of $F_N/\delta = 1\,600$ for the pooling of our three data sets is summarized in Table A1-2.

## 7. BIBLIOGRAPHY

Cochran, W.G. "Approximate Significance Levels of the Behrens-Fisher Test." *Biometrics* 10 (1964): 191-195.

**Table A1-2. Example of confidence interval calculation**

| *Description* | *Function* | *Datum* | *Hardwall* | *Silenced* |
|---|---|---|---|---|
| Reference thrust | $F_N/\delta$ | — | 1 600 | 1 600 |
| 90 per cent confidence interval about the mean | $CI_{90}$ | 0.3183 | 0.4817 | 0.2128 |
| Number of data points | $n$ | 6 | 23 | 6 |
| Degree of curve fit | $k$ | 0 | 2 | 1 |
| Number of independent variables | $K$ | 0 | 2 | 1 |
| Number of degrees of freedom | $n - K - 1$ | 5 | 20 | 4 |
| Student's t-distribution | t | 2.015 | 1.725 | 2.132 |
| $Z$ | $CI_{90}/t$ | 0.1580 | 0.2792 | 0.09981 |
| $Z^2$ | $(CI_{90}/t)^2$ | 2.4953E–2 | 7.7979E–2 | 9.9625E–3 |
| $Z^2t$ | $(CI_{90}/t)^2t$ | 5.0280E–2 | 0.1345 | 2.1240E–2 |
| $\Sigma Z^2$ | — | — | 0.1129 | — |
| $\Sigma(Z^2\mathrm{t})$ | — | — | 0.2060 | — |
| $T$ | $\Sigma(Z^2t)/\Sigma Z^2$ | — | 1.8248 | — |
| $\sqrt{\Sigma Z^2}$ | — | — | 0.3360 | — |
| $CI$ | $\sqrt[T]{\Sigma Z^2}$ | — | 0.6131 | — |

Kendall, M.G. and A. Stuart. *The Advanced Theory of Statistics*. Volumes 1, 2 and 3. New York: Hafner, 1971.

Kendall, M.G. and G. U. Yule. *An Introduction to the Theory of Statistics.* 14th ed. New York: Griffin, 1950.

Rose, D.M. and F.W. Scholz. *Statistical Analysis of Cumulative Shipper-Receiver Data.* U.S. Nuclear Regulatory Commission, Division of Facility Operations, Office of Nuclear Regulatory Research, Washington, D.C. 20555, 1983. NUREG/CR-2819. NRC FIN B1076.

Snedecor, G.W. and W.G. Cochran. *Statistical Methods*. 6th ed. Arnes, Iowa: The Iowa State University Press, 1968.

Walpole, R.E. and R.H. Myers. *Probability and Statistics for Engineers and Scientists*. New York: MacMillan, 1972.

Wonnacott, T.H. and R.J. Wonnacott. *Introductory Statistics*. 5th ed. N.p.: John Wiley & Sons, 1990.

## 8. STUDENT'S T-DISTRIBUTION (FOR 90 PER CENT CONFIDENCE) FOR VARIOUS DEGREES OF FREEDOM

The values in the Student's t-distribution to give a probability of 0.95 so that the population mean value, $\mu$, is such that:

$$\mu \le \bar{y} + t_{.95,\,\zeta}\frac{s}{\sqrt{n}}$$

and thus a probability of 0.90 (90 per cent) that

$$y - t_{.95,\,\zeta}\frac{s}{\sqrt{n}} \le \mu \le \bar{y} = t_{.95,\,\zeta}\frac{s}{\sqrt{n}} \;.$$

### Table A1-3. Student's t-distribution (for 90 per cent confidence) for various degrees of freedom.

| *Degrees of Freedom ()* | $t_{0.95,}$ |
|---|---|
| 1 | 6.314 |
| 2 | 2.920 |
| 3 | 2.353 |
| 4 | 2.132 |
| 5 | 2.015 |
| 6 | 1.943 |
| 7 | 1.895 |
| 8 | 1.860 |
| 9 | 1.833 |
| 10 | 1.812 |
| 12 | 1.782 |
| 14 | 1.761 |
| 16 | 1.746 |
| 18 | 1.734 |
| 20 | 1.725 |
| 24 | 1.711 |
| 30 | 1.697 |
| 60 | 1.671 |
| >60 | 1.645 |

# Appendix 2

# IDENTIFICATION OF SPECTRAL IRREGULARITIES

## 1. INTRODUCTION

1.1 Spectral irregularities which are not produced by aircraft noise sources may cause tone corrections to be generated when the procedures of 4.3 of Appendix 1 and Appendix 2, respectively, of Annex 16 — *Environmental Protection*, Volume I — *Aircraft Noise* are used. These spectral irregularities may be caused by:

a) the reflected sound energy from the ground plane beneath the microphone mounted at 1.2 m above it, interfering with the direct sound energy from the aircraft. The re-enforcing and destructive effects of this interference is strongest at lower frequencies, typically 100 Hz to 200 Hz and diminishes with increasing frequency. The local peaks in the one-third octave spectra of such signals are termed pseudotones. Above 800 Hz this interference effect is usually insufficient to generate a tone correction when the Annex 16, Volume I tone correction procedure is used;

b) small perturbations in the propagation of aircraft noise when analysed with one-third octave bandwidth filters; or

c) the data processing adjustments and corrections such as the background noise adjustment method and the adjustment for atmospheric attenuation. In the case of the latter, the atmospheric attenuation coefficients ($\alpha$) given in SAE ARP 866A ascribe $\alpha$ values at 4 kHz to the centre frequency of the one-third octave band whereas at 5 kHz the value of $\alpha$ is ascribed to the lower pass frequency of the one-third octave. This difference is sufficient in some cases to generate a tone correction.

1.2 The inclusion of a tone correction factor in the computation of Effective Perceived Noise Level (EPNL) accounts for the subjective response to the presence of pronounced spectral irregularities. Tones generated by aircraft noise sources are those for which the application of tone correction factors are appropriate. Tone correction factors which result from spectral irregularities, i.e. false tones produced by any of the causes cited in 1.1 may be disregarded. This appendix describes methods which have been approved for detecting and removing the effects of such spectral irregularities. Approval of the use of any of these methods however remains with the certificating authority.

## 2. METHODS FOR IDENTIFYING FALSE TONES

### 2.1 Frequency tracking

2.1.1 Frequency tracking of flyover noise data is useful for the frequency tracking of spectral irregularities. The observed frequency of aeroplane noise sources decrease continuously during the flyover due to Doppler frequency shift, $f_{DOPP}$, where:

$$f_{DOPP} = \frac{f}{1 - M\cos\lambda}$$

where

$f$ is the frequency of the noise at source

$M$ is the Mach number of the aeroplane

$\lambda$ is the angle between the flight path in the direction of flight and a line connecting the source and observer at the time of emission.

2.1.2 Reflection-related effects in the spectra, i.e. pseudotones, decrease in frequency prior to, and increase in frequency after passing overhead or abeam the microphone. Spectral irregularities caused by perturbations during the propagation of the noise from the aeroplane to the microphone tend to be random in nature, in contrast to the Doppler effect. These differing characteristics can be used to separate source tones from false tones.

### 2.2 Narrow band analysis

Narrow band analysis with filter bandwidths narrower than those of one-third octaves is useful for identifying false tones. For example, when the analysis is produced such that the spectral noise levels at an instance are presented in terms of image intensity on a line, the overall flyover analysis clearly indicates the Doppler-shifted aeroplane tones and those due to reflection as described in 2.1.

### 2.3 Microphone mounting height

Comparison of one-third octave spectra of measurements taken using the 1.2 m high microphone and corresponding data obtained from a neighbouring microphone mounted flush on a hard reflecting surface, a configuration similar to that described in 4.4 of Appendix 6 of Annex 16, Volume I, or at a height substantially greater than 1.2 m, such as 10 m, may be used to identify false tones. Changes to the microphone height alters the interference spectra irregularities from the frequency range of data from the 1.2 m high microphone, and when a comparison is made between the two data sets collected at the same time, noise source tones can be separated from any false tones which may be present.

### 2.4 Inspection of noise time histories

Spectral irregularities which arise following data correction or adjustment (as described in 1.1 b)) will occur in the frequency range of between 1 kHz to 10 kHz and the resulting false tone corrections will normally vary in magnitude between 0.2 dB to 0.6 dB. Time histories of Perceived Noise Levels (PNLs) and Tone Corrected Perceived Noise Levels (PNLT), which exhibit constant level differences, are often indicative of the presence of false tone corrections. Supplementary narrow band analysis is useful in demonstrating that such tone corrections are not due to aeroplane-generated noise.

## 3. TREATMENT OF FALSE TONES

When spectral irregularities give rise to false tones which are identified by, for example, the methods described in Section 2 of this appendix, their value, when computed according to Step 9 of the tone correction calculation described in 4.3 of Appendix 2 of Annex 16, Volume I may be set to zero.

# Appendix 3

# GUIDELINES FOR ADJUSTMENT OF AIRCRAFT NOISE LEVELS FOR THE EFFECTS OF BACKGROUND NOISE

## 1. 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 Effective Perceived Noise Level (EPNL) values. Adjustment procedures should include the following components:

- testing to determine which portions of the spectral time history, if any, are obscured;
- adjusted unobscured levels to determine the aircraft sound levels that would have been measured in the absence of background noise; and
- replacement or reconstruction of 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. 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, including equations and descriptions of time and frequency extrapolation methods (see 3.2.10 of this appendix). 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, including requirements and limitations (see 4.1 of this appendix) and other special considerations (see 4.2 through 4.4 of this appendix).

## 2. 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 digitization noise, can obscure the aircraft noise signal, while others, such as ambient noise, can also contribute energy to the measured aircraft noise signal.

***Energy subtraction***. Subtraction of one sound pressure level from another, on an energy basis, in the form of the following:

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

where $L_A$ and $L_B$ are two sound pressure levels in decibels, with $L_B$ 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.

***High frequency bands***. The twelve bands from 800 Hz through 10 kHz inclusive. (Also see "low frequency bands").

***LGB (last good band)***. In the adjustment methodology presented in Section 3, for any aircraft one-third octave band spectrum, the LGB is 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 the 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, record/playback, 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.

***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. BACKGROUND NOISE ADJUSTMENT PROCEDURE

### 3.1 Assumptions

a) 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.

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

c) Due to the assumptions cited in a) and b), 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.

d) If, on occasion, a valid level occurs in a band with higher centre frequency than the LGB, its presence will most likely be due to small variations in the pre-detection levels and/or due to levels of the measured aircraft one-third-octave band spectrum being close to the levels of the background noise in general, so 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 with higher centre frequency than the 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 analysing ambient noise over a representative period of time (30 seconds or more). 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 in order 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 of the settings 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). These 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 should therefore 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 or LGB.* For each half-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. According to the masking limits specified in 4.2 a) 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 half-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:

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

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*. In 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 arithmetic average of the adjusted levels of the adjacent valid bands may be used in place of the masked level. If the arithmetic 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 frequencies higher than LGB for each spectral record. One-third octave band atmospheric absorption coefficients (either in dB per 1 000 feet or in 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.

3.2.10.1 *Frequency extrapolation method*

For a spectrum where the 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:

$$\begin{aligned} Lx_{i,k} = {} & L_{j,k} + \alpha_j \times \frac{SR_k}{100} - \alpha_{j_{REF}} \\ & \times \frac{60}{100} + 20\log 10\frac{SR_k}{60} + \alpha_{i_{REF}} \\ & \times \frac{60}{100} - \alpha_i \times \frac{SR_k}{100} + 20\log 10\frac{60}{SR_k} \end{aligned}$$

which can be reduced to:

$$\begin{aligned} Lx_{i,k} = {} & L_{j,k} + [\alpha_j - \alpha_i] \times \frac{SR_k}{100} \\ & + \left[\alpha_{i_{REF}} - \alpha_{j_{REF}}\right] \times \frac{60}{100} \end{aligned}$$

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.

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

$\alpha_i$ is the test day atmospheric absorption coefficient (dB per 100 m) for band $i$;

$\alpha_{j_{REF}}$ is the reference (25°C, 70 per cent RH) atmospheric absorption coefficient (dB per 100 m) for LGB;

$\alpha_{i_{REF}}$ is the reference (25°C, 70 per cent RH) atmospheric absorption coefficient (dB per 100 m) for masked band $i$; and

$SR_k$ 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 m under reference conditions (*25°C, 70 per cent 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 and then adjusted using reference propagation effects to the 60-m 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 m;

3) a new source level is determined for each masked high frequency band by removing the associated reference day propagation effects; and

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.

3.2.10.2 *Time extrapolation method*

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 with frequencies greater than that of LGB must be reconstructed using this time extrapolation method. Any time-extrapolated levels should be categorized as reconstructed. Reconstruct the levels for the masked bands by using the following equation:

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

where:

$Lx_{i,k}$ is the time-extrapolated level in dB for masked 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 metres 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 metres at the time of noise emission for spectral record *k*, between the aircraft and the microphone; and

$\alpha_i$ 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 omni-directional during the aircraft pass-by.

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 Tone Corrected Perceived Noise Level (PNLT) time history described in Annex 16, Volume I, Appendix 2, 4.3. 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 Annex 16, Volume I, Appendix 2, 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. 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 it is used. The adjustment procedure presented in 3.2 of this appendix includes applicable limitations and requirements. Those limitations and requirements which apply to all methodologies are described as follows.

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

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, these 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 3.2.10.1 of this appendix) must be performed on all consecutive masked bands with 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 3.2.10.2 of this appendix) must be performed on all consecutive masked bands with nominal frequencies greater than 630 Hz.

4.1.6 In 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 when counting the masked levels in 4.2 of this appendix.

### 4.2 Rejection of spectra due to masking

A spectrum becomes invalid if the following conditions prevail:

a) if, after any reconstruction of masked bands, more than four one-third octave bands retain masked values;

b) for records within one second of the record associated with the $\text{PNLT}_{\text{MAX}}$ spectrum (i.e. five half-second data records), if more than four high frequency bands require reconstruction; or

c) if the LGB is located at or below the 3 150 Hz one-third octave band when the example background noise adjustment procedure presented in 3.2 of this appendix is used.

*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.*

### 4.3 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 the adjustment for background noise may be eliminated by either one of the following two methods, as appropriate.

a) When the example background noise adjustment procedure presented in 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, i.e. "LGB"), the band labelled as LGB should be treated as the last band of the tone correction calculation (in the manner prescribed for the 10 kHz band in Annex 16, Volume I, Appendix 2, 4.2.1, including calculation of a new slope for the band above LGB that equals the slope of the band at LGB [i.e. $s'(LGB+1, k) = s'(LGB, k)$] in Step 5 of the tone correction procedure); or

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

*Note.— All band levels within a spectrum, whether adjusted, reconstructed or masked, must be included in the computation of the Perceived Noise Level (PNL) value for that spectrum.*

### 4.4 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 3.2 of this appendix apply to both test and reference data sets.

# Appendix 4

# REFERENCE TABLES AND FIGURE USED IN THE MANUAL CALCULATION OF EFFECTIVE PERCEIVED NOISE LEVEL

This appendix contains material useful in the manual calculation of effective perceived noise level. Such manual calculations are often required to verify the accuracy of computer programs used for calculating noise certification levels.

## Table A4-1. Perceived noisiness (noys) as a function of sound pressure level

One-third octave band centre frequencies (Hz)

| SPL | 50 | 63 | 80 | 100 | 125 | 160 | 200 | 250 | 315 | 400 | 500 | 630 | 800 | 1000 | 1250 | 1600 | 2000 | 2500 | 3150 | 4000 | 5000 | 6300 | 8000 | 10000 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | | | | | | | | | | | | | | | | | | | 0.10 | | | | | |
| 5 | | | | | | | | | | | | | | | | | | 0.10 | 0.11 | 0.10 | | | | |
| 6 | | | | | | | | | | | | | | | | | | 0.11 | 0.12 | 0.11 | 0.10 | | | |
| 7 | | | | | | | | | | | | | | | | | | 0.12 | 0.14 | 0.13 | 0.11 | | | |
| 8 | | | | | | | | | | | | | | | | | | 0.14 | 0.16 | 0.14 | 0.13 | | | |
| 9 | | | | | | | | | | | | | | | | | 0.10 | 0.16 | 0.17 | 0.16 | 0.14 | | | |
| 10 | | | | | | | | | | | | | | | | | 0.11 | 0.17 | 0.19 | 0.18 | 0.16 | 0.10 | | |
| 11 | | | | | | | | | | | | | | | | | 0.13 | 0.19 | 0.22 | 0.21 | 0.18 | 0.12 | | |
| 12 | | | | | | | | | | | | | | | | 0.10 | 0.14 | 0.22 | 0.24 | 0.24 | 0.21 | 0.14 | | |
| 13 | | | | | | | | | | | | | | | | 0.11 | 0.16 | 0.24 | 0.27 | 0.27 | 0.24 | 0.16 | | |
| 14 | | | | | | | | | | | | | | | | 0.13 | 0.18 | 0.27 | 0.30 | 0.30 | 0.27 | 0.19 | | |
| 15 | | | | | | | | | | | | | | | 0.10 | 0.14 | 0.21 | 0.30 | 0.33 | 0.33 | 0.30 | 0.22 | | |
| 16 | | | | | | | | | | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.11 | 0.16 | 0.24 | 0.33 | 0.35 | 0.35 | 0.33 | 0.26 | | |
| 17 | | | | | | | | | | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.13 | 0.18 | 0.27 | 0.35 | 0.38 | 0.38 | 0.35 | 0.30 | 0.10 | |
| 18 | | | | | | | | | 0.10 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.15 | 0.21 | 0.30 | 0.38 | 0.41 | 0.41 | 0.38 | 0.33 | 0.12 | |
| 19 | | | | | | | | | 0.11 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.17 | 0.24 | 0.33 | 0.41 | 0.45 | 0.45 | 0.41 | 0.36 | 0.14 | |
| 20 | | | | | | | | | 0.13 | 0.16 | 0.16 | 0.16 | 0.16 | 0.16 | 0.20 | 0.27 | 0.36 | 0.45 | 0.49 | 0.49 | 0.45 | 0.39 | 0.17 | |
| 21 | | | | | | | | 0.10 | 0.14 | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 | 0.23 | 0.30 | 0.39 | 0.49 | 0.53 | 0.53 | 0.49 | 0.42 | 0.21 | 0.10 |
| 22 | | | | | | | | 0.11 | 0.16 | 0.21 | 0.21 | 0.21 | 0.21 | 0.21 | 0.26 | 0.33 | 0.42 | 0.53 | 0.57 | 0.57 | 0.53 | 0.46 | 0.25 | 0.11 |
| 23 | | | | | | | | 0.13 | 0.18 | 0.24 | 0.24 | 0.24 | 0.24 | 0.24 | 0.30 | 0.36 | 0.46 | 0.57 | 0.62 | 0.62 | 0.57 | 0.50 | 0.30 | 0.13 |
| 24 | | | | | | | 0.10 | 0.14 | 0.21 | 0.27 | 0.27 | 0.27 | 0.27 | 0.27 | 0.33 | 0.40 | 0.50 | 0.62 | 0.67 | 0.67 | 0.62 | 0.55 | 0.33 | 0.15 |
| 25 | | | | | | | 0.11 | 0.16 | 0.24 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.35 | 0.43 | 0.55 | 0.67 | 0.73 | 0.73 | 0.67 | 0.60 | 0.36 | 0.17 |
| 26 | | | | | | | 0.13 | 0.18 | 0.27 | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 | 0.38 | 0.48 | 0.60 | 0.73 | 0.79 | 0.79 | 0.73 | 0.65 | 0.39 | 0.20 |
| 27 | | | | | | 0.10 | 0.14 | 0.21 | 0.30 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.41 | 0.52 | 0.65 | 0.79 | 0.85 | 0.85 | 0.79 | 0.71 | 0.42 | 0.23 |
| 28 | | | | | | 0.11 | 0.16 | 0.24 | 0.33 | 0.38 | 0.38 | 0.38 | 0.38 | 0.38 | 0.45 | 0.57 | 0.71 | 0.85 | 0.92 | 0.92 | 0.85 | 0.77 | 0.46 | 0.26 |
| 29 | | | | | | 0.13 | 0.18 | 0.27 | 0.35 | 0.41 | 0.41 | 0.41 | 0.41 | 0.41 | 0.49 | 0.63 | 0.77 | 0.92 | 1.00 | 1.00 | 0.92 | 0.84 | 0.50 | 0.30 |
| 30 | | | | | 0.10 | 0.14 | 0.21 | 0.30 | 0.38 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.53 | 0.69 | 0.84 | 1.00 | 1.07 | 1.07 | 1.00 | 0.92 | 0.55 | 0.33 |
| 31 | | | | | 0.11 | 0.16 | 0.24 | 0.33 | 0.41 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.57 | 0.76 | 0.93 | 1.07 | 1.15 | 1.15 | 1.07 | 1.00 | 0.60 | 0.37 |
| 32 | | | | | 0.13 | 0.18 | 0.27 | 0.36 | 0.45 | 0.53 | 0.53 | 0.53 | 0.53 | 0.53 | 0.62 | 0.83 | 1.00 | 1.15 | 1.23 | 1.23 | 1.15 | 1.07 | 0.65 | 0.41 |
| 33 | | | | | 0.14 | 0.21 | 0.30 | 0.39 | 0.49 | 0.57 | 0.57 | 0.57 | 0.57 | 0.57 | 0.67 | 0.91 | 1.07 | 1.23 | 1.32 | 1.32 | 1.23 | 1.15 | 0.71 | 0.45 |
| 34 | | | | 0.10 | 0.16 | 0.24 | 0.33 | 0.42 | 0.53 | 0.62 | 0.62 | 0.62 | 0.62 | 0.62 | 0.73 | 1.00 | 1.15 | 1.32 | 1.41 | 1.41 | 1.32 | 1.23 | 0.77 | 0.50 |
| 35 | | | | 0.11 | 0.18 | 0.27 | 0.36 | 0.46 | 0.57 | 0.67 | 0.67 | 0.67 | 0.67 | 0.67 | 0.79 | 1.07 | 1.23 | 1.41 | 1.51 | 1.51 | 1.41 | 1.32 | 0.84 | 0.55 |
| 36 | | | | 0.13 | 0.21 | 0.30 | 0.40 | 0.50 | 0.62 | 0.73 | 0.73 | 0.73 | 0.73 | 0.73 | 0.85 | 1.15 | 1.32 | 1.51 | 1.62 | 1.62 | 1.51 | 1.41 | 0.92 | 0.61 |
| 37 | | | | 0.15 | 0.24 | 0.33 | 0.43 | 0.55 | 0.67 | 0.79 | 0.79 | 0.79 | 0.79 | 0.79 | 0.92 | 1.23 | 1.41 | 1.62 | 1.74 | 1.74 | 1.62 | 1.51 | 1.00 | 0.67 |
| 38 | | | | 0.17 | 0.27 | 0.37 | 0.48 | 0.60 | 0.73 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 1.00 | 1.32 | 1.51 | 1.74 | 1.86 | 1.86 | 1.74 | 1.62 | 1.10 | 0.74 |
| 39 | | | 0.10 | 0.20 | 0.30 | 0.41 | 0.52 | 0.65 | 0.79 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 1.07 | 1.41 | 1.62 | 1.86 | 1.99 | 1.99 | 1.86 | 1.74 | 1.21 | 0.82 |
| 40 | | | 0.12 | 0.23 | 0.33 | 0.45 | 0.57 | 0.71 | 0.85 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.15 | 1.51 | 1.74 | 1.99 | 2.14 | 2.14 | 1.99 | 1.86 | 1.34 | 0.90 |
| 41 | | | 0.14 | 0.26 | 0.37 | 0.50 | 0.63 | 0.77 | 0.92 | 1.07 | 1.07 | 1.07 | 1.07 | 1.07 | 1.23 | 1.62 | 1.86 | 2.14 | 2.29 | 2.29 | 2.14 | 1.99 | 1.48 | 1.00 |
| 42 | | | 0.16 | 0.30 | 0.41 | 0.55 | 0.69 | 0.84 | 1.00 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.32 | 1.74 | 1.99 | 2.29 | 2.45 | 2.45 | 2.29 | 2.14 | 1.63 | 1.10 |
| 43 | | | 0.19 | 0.33 | 0.45 | 0.61 | 0.76 | 0.92 | 1.07 | 1.23 | 1.23 | 1.23 | 1.23 | 1.23 | 1.41 | 1.86 | 2.14 | 2.45 | 2.63 | 2.63 | 2.45 | 2.29 | 1.79 | 1.21 |
| 44 | | 0.10 | 0.22 | 0.37 | 0.50 | 0.67 | 0.83 | 1.00 | 1.15 | 1.32 | 1.32 | 1.32 | 1.32 | 1.32 | 1.52 | 1.99 | 2.29 | 2.63 | 2.81 | 2.81 | 2.63 | 2.45 | 1.99 | 1.34 |
| 45 | | 0.12 | 0.26 | 0.42 | 0.55 | 0.74 | 0.91 | 1.08 | 1.24 | 1.41 | 1.41 | 1.41 | 1.41 | 1.41 | 1.62 | 2.14 | 2.45 | 2.81 | 3.02 | 3.02 | 2.81 | 2.63 | 2.14 | 1.48 |
| 46 | | 0.14 | 0.30 | 0.46 | 0.61 | 0.82 | 1.00 | 1.16 | 1.33 | 1.52 | 1.52 | 1.52 | 1.52 | 1.52 | 1.74 | 2.29 | 2.63 | 3.02 | 3.23 | 3.23 | 3.02 | 2.81 | 2.29 | 1.63 |
| 47 | | 0.16 | 0.34 | 0.52 | 0.67 | 0.90 | 1.08 | 1.25 | 1.42 | 1.62 | 1.62 | 1.62 | 1.62 | 1.62 | 1.87 | 2.45 | 2.81 | 3.23 | 3.46 | 3.46 | 3.23 | 3.02 | 2.45 | 1.79 |
| 48 | | 0.19 | 0.38 | 0.58 | 0.74 | 1.00 | 1.17 | 1.34 | 1.53 | 1.74 | 1.74 | 1.74 | 1.74 | 1.74 | 2.00 | 2.63 | 3.02 | 3.46 | 3.71 | 3.71 | 3.46 | 3.23 | 2.63 | 1.98 |
| 49 | 0.10 | 0.22 | 0.43 | 0.65 | 0.82 | 1.08 | 1.26 | 1.45 | 1.64 | 1.87 | 1.87 | 1.87 | 1.87 | 1.87 | 2.14 | 2.81 | 3.23 | 3.71 | 3.97 | 3.97 | 3.71 | 3.46 | 2.81 | 2.18 |
| 50 | 0.12 | 0.26 | 0.49 | 0.72 | 0.90 | 1.17 | 1.36 | 1.56 | 1.76 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.30 | 3.02 | 3.46 | 3.97 | 4.26 | 4.26 | 3.97 | 3.71 | 3.02 | 2.40 |
| 51 | 0.14 | 0.30 | 0.55 | 0.80 | 1.00 | 1.26 | 1.47 | 1.68 | 1.89 | 2.14 | 2.14 | 2.14 | 2.14 | 2.14 | 2.46 | 3.23 | 3.71 | 4.26 | 4.56 | 4.56 | 4.26 | 3.97 | 3.23 | 2.63 |
| 52 | 0.17 | 0.34 | 0.62 | 0.90 | 1.08 | 1.36 | 1.58 | 1.80 | 2.03 | 2.30 | 2.30 | 2.30 | 2.30 | 2.30 | 2.64 | 3.46 | 3.97 | 4.56 | 4.89 | 4.89 | 4.56 | 4.26 | 3.46 | 2.81 |
| 53 | 0.21 | 0.39 | 0.70 | 1.00 | 1.18 | 1.47 | 1.71 | 1.94 | 2.17 | 2.46 | 2.46 | 2.46 | 2.46 | 2.46 | 2.83 | 3.71 | 4.26 | 4.89 | 5.24 | 5.24 | 4.89 | 4.56 | 3.71 | 3.02 |
| 54 | 0.25 | 0.45 | 0.79 | 1.09 | 1.28 | 1.58 | 1.85 | 2.09 | 2.33 | 2.64 | 2.64 | 2.64 | 2.64 | 2.64 | 3.03 | 3.97 | 4.56 | 5.24 | 5.61 | 5.61 | 5.24 | 4.89 | 3.97 | 3.23 |
| 55 | 0.30 | 0.51 | 0.89 | 1.15 | 1.35 | 1.71 | 2.00 | 2.25 | 2.50 | 2.83 | 2.83 | 2.83 | 2.83 | 2.83 | 3.25 | 4.26 | 4.89 | 5.61 | 6.01 | 6.01 | 5.61 | 5.24 | 4.26 | 3.46 |
| 56 | 0.34 | 0.59 | 1.00 | 1.29 | 1.50 | 1.85 | 2.15 | 2.42 | 2.69 | 3.03 | 3.03 | 3.03 | 3.03 | 3.03 | 3.48 | 4.56 | 5.24 | 6.01 | 6.44 | 6.44 | 6.01 | 5.61 | 4.56 | 3.71 |
| 57 | 0.39 | 0.67 | 1.09 | 1.40 | 1.63 | 2.00 | 2.33 | 2.61 | 2.88 | 3.25 | 3.25 | 3.25 | 3.25 | 3.25 | 3.73 | 4.89 | 5.61 | 6.44 | 6.90 | 6.90 | 6.44 | 6.01 | 4.89 | 3.97 |
| 58 | 0.45 | 0.77 | 1.18 | 1.53 | 1.77 | 2.15 | 2.51 | 2.81 | 3.10 | 3.48 | 3.48 | 3.48 | 3.48 | 3.48 | 4.00 | 5.24 | 6.01 | 6.90 | 7.39 | 7.39 | 6.90 | 6.44 | 5.24 | 4.26 |
| 59 | 0.51 | 0.87 | 1.29 | 1.66 | 1.92 | 2.33 | 2.71 | 3.03 | 3.32 | 3.73 | 3.73 | 3.73 | 3.73 | 3.73 | 4.29 | 5.61 | 6.44 | 7.39 | 7.92 | 7.92 | 7.39 | 6.90 | 5.61 | 4.56 |

One-third octave band centre frequencies (Hz)

| SPL | 50 | 63 | 80 | 100 | 125 | 160 | 200 | 250 | 315 | 400 | 500 | 630 | 800 | 1000 | 1250 | 1600 | 2000 | 2500 | 3150 | 4000 | 5000 | 6300 | 8000 | 10000 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 60 | 0.59 | 1.00 | 1.40 | 1.81 | 2.08 | 2.51 | 2.93 | 3.26 | 3.57 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.59 | 6.01 | 6.90 | 7.92 | 8.49 | 8.49 | 7.92 | 7.39 | 6.01 | 4.89 |
| 61 | 0.67 | 1.10 | 1.53 | 1.97 | 2.26 | 2.71 | 3.16 | 3.51 | 3.83 | 4.29 | 4.29 | 4.29 | 4.29 | 4.29 | 4.92 | 6.44 | 7.39 | 8.49 | 9.09 | 9.09 | 8.49 | 7.92 | 6.44 | 5.24 |
| 62 | 0.77 | 1.21 | 1.66 | 2.15 | 2.45 | 2.93 | 3.41 | 3.78 | 4.11 | 4.59 | 4.59 | 4.59 | 4.59 | 4.59 | 5.28 | 6.90 | 7.92 | 9.09 | 9.74 | 9.74 | 9.09 | 8.49 | 6.90 | 5.61 |
| 63 | 0.87 | 1.32 | 1.81 | 2.34 | 2.65 | 3.16 | 3.69 | 4.06 | 4.41 | 4.92 | 4.92 | 4.92 | 4.92 | 4.92 | 5.66 | 7.39 | 8.49 | 9.74 | 10.4 | 10.4 | 9.74 | 9.09 | 7.39 | 6.01 |
| 64 | 1.00 | 1.45 | 1.97 | 2.54 | 2.88 | 3.41 | 3.98 | 4.38 | 4.73 | 5.28 | 5.28 | 5.28 | 5.28 | 5.28 | 6.06 | 7.92 | 9.09 | 10.4 | 11.2 | 11.2 | 10.4 | 9.74 | 7.92 | 6.44 |
| 65 | 1.11 | 1.60 | 2.15 | 2.77 | 3.12 | 3.69 | 4.30 | 4.71 | 5.08 | 5.66 | 5.66 | 5.66 | 5.66 | 5.66 | 6.50 | 8.49 | 9.74 | 11.2 | 12.0 | 12.0 | 11.2 | 10.4 | 8.49 | 6.90 |
| 66 | 1.22 | 1.75 | 2.34 | 3.01 | 3.39 | 3.98 | 4.64 | 5.07 | 5.45 | 6.06 | 6.06 | 6.06 | 6.06 | 6.06 | 6.96 | 9.09 | 10.4 | 12.0 | 12.8 | 12.8 | 12.0 | 11.2 | 9.09 | 7.39 |
| 67 | 1.35 | 1.92 | 2.54 | 3.28 | 3.68 | 4.30 | 5.01 | 5.46 | 5.85 | 6.50 | 6.50 | 6.50 | 6.50 | 6.50 | 7.46 | 9.74 | 11.2 | 12.8 | 13.8 | 13.8 | 12.8 | 12.0 | 9.74 | 7.92 |
| 68 | 1.49 | 2.11 | 2.77 | 3.57 | 3.99 | 4.64 | 5.41 | 5.88 | 6.27 | 6.96 | 6.96 | 6.96 | 6.96 | 6.96 | 8.00 | 10.4 | 12.0 | 13.8 | 14.7 | 14.7 | 13.8 | 12.8 | 10.4 | 8.49 |
| 69 | 1.65 | 2.32 | 3.01 | 3.88 | 4.33 | 5.01 | 5.84 | 6.33 | 6.73 | 7.46 | 7.46 | 7.46 | 7.46 | 7.46 | 8.57 | 11.2 | 12.8 | 14.7 | 15.8 | 15.8 | 14.7 | 13.8 | 11.2 | 9.09 |
| 70 | 1.82 | 2.55 | 3.28 | 4.23 | 4.69 | 5.41 | 6.31 | 6.81 | 7.23 | 8.00 | 8.00 | 8.00 | 8.00 | 8.00 | 9.19 | 12.0 | 13.8 | 15.8 | 16.9 | 16.9 | 15.8 | 14.7 | 12.0 | 9.74 |
| 71 | 2.02 | 2.79 | 3.57 | 4.60 | 5.09 | 5.84 | 6.81 | 7.33 | 7.75 | 8.57 | 8.57 | 8.57 | 8.57 | 8.57 | 9.85 | 12.8 | 14.7 | 16.9 | 18.1 | 18.1 | 16.9 | 15.8 | 12.8 | 10.4 |
| 72 | 2.23 | 3.07 | 3.88 | 5.01 | 5.52 | 6,31 | 7.36 | 7.90 | 8.32 | 9.19 | 9.19 | 9.19 | 9.19 | 9.19 | 10.6 | 13.8 | 15.8 | 18.1 | 19.4 | 19.4 | 18.1 | 16.9 | 13.8 | 11.2 |
| 73 | 2.46 | 3.37 | 4.23 | 5.45 | 5.99 | 6.81 | 7.94 | 8.50 | 8.93 | 9.85 | 9.85 | 9.85 | 9.85 | 9.85 | 11.3 | 14.7 | 16.9 | 19.4 | 20.8 | 20.8 | 19.4 | 18.1 | 14.7 | 12.0 |
| 74 | 2.72 | 3.70 | 4.60 | 5.94 | 6.50 | 7.36 | 8.57 | 9.15 | 9.59 | 10.6 | 10.6 | 10.6 | 10.6 | 10.6 | 12.1 | 15.8 | 18.1 | 20.8 | 22.3 | 22.3 | 20.8 | 19.4 | 15.8 | 12.8 |
| 75 | 3.01 | 4.06 | 5.01 | 6.46 | 7.05 | 7.94 | 9.19 | 9.85 | 10.3 | 11.3 | 11.3 | 11.3 | 11.3 | 11.3 | 13.0 | 16.9 | 19.4 | 22.3 | 23.9 | 23.9 | 22.3 | 20.8 | 16.9 | 13.8 |
| 76 | 3.32 | 4.46 | 5.45 | 7.03 | 7.65 | 8.57 | 9.85 | 10.6 | 11.0 | 12.1 | 12.1 | 12.1 | 12.1 | 12.1 | 13.9 | 18.1 | 20.8 | 23.9 | 25.6 | 25.6 | 23.9 | 22.3 | 18.1 | 14.7 |
| 77 | 3.67 | 4.89 | 5.94 | 7.66 | 8.29 | 9.19 | 10.6 | 11.3 | 11.8 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 14.9 | 19.4 | 22.3 | 25.6 | 27.4 | 27.4 | 25.6 | 23.9 | 19.4 | 15.8 |
| 78 | 4.06 | 5.37 | 6.46 | 8.33 | 9.00 | 9.85 | 11.3 | 12.1 | 12.7 | 13.9 | 13.9 | 13.9 | 13.9 | 13.9 | 16.0 | 20.8 | 23.9 | 27.4 | 29.4 | 29.4 | 27.4 | 25.6 | 20.8 | 16.9 |
| 79 | 4.49 | 5.90 | 7.03 | 9.07 | 9.76 | 10.6 | 12.1 | 13.0 | 13.6 | 14.9 | 14.9 | 14.9 | 14.9 | 14.9 | 17.1 | 22.3 | 25.6 | 29.4 | 31.5 | 31.5 | 29.4 | 27.4 | 22.3 | 18.1 |
| 80 | 4.96 | 6.48 | 7.66 | 9.85 | 10.6 | 11.3 | 13.0 | 13.9 | 14.6 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 18.4 | 23.9 | 27.4 | 31.5 | 33.7 | 33.7 | 31.5 | 29.4 | 23.9 | 19.4 |
| 81 | 5.48 | 7.11 | 8.33 | 10.6 | 11.3 | 12.1 | 13.9 | 14.9 | 15.7 | 17.1 | 17.1 | 17.1 | 17.1 | 17.1 | 19.7 | 25.6 | 29.4 | 33.7 | 36.1 | 36.1 | 33.7 | 31.5 | 25.6 | 20.8 |
| 82 | 6.06 | 7.81 | 9.07 | 11.3 | 12.1 | 13.0 | 14.9 | 16.0 | 16.9 | 18.4 | 18.4 | 18.4 | 18.4 | 18.4 | 21.1 | 27.4 | 31.5 | 36.1 | 38.7 | 38.7 | 36.1 | 33.7 | 27.4 | 22.3 |
| 83 | 6.70 | 8.57 | 9.87 | 12.1 | 13.0 | 13.9 | 16.0 | 17.1 | 18.1 | 19.7 | 19.7 | 19.7 | 19.7 | 19.7 | 22.6 | 29.4 | 33.7 | 38.7 | 41.5 | 41.5 | 38.7 | 36.1 | 29.4 | 23.9 |
| 84 | 7.41 | 9.41 | 10.7 | 13.0 | 13.9 | 14.9 | 17.1 | 18.4 | 19.4 | 21.1 | 21.1 | 21.1 | 21.1 | 21.1 | 24.3 | 31.5 | 36.1 | 41.5 | 44.4 | 44.4 | 41.5 | 38.7 | 31.5 | 25.6 |
| 85 | 8.19 | 10.3 | 11.7 | 13.9 | 14.9 | 16.0 | 18.4 | 19.7 | 20.8 | 22.6 | 22.6 | 22.6 | 22.6 | 22.6 | 26.0 | 33.7 | 38.7 | 44.4 | 47.6 | 47.6 | 44.4 | 41.5 | 33.7 | 27.4 |
| 86 | 9.95 | 11.3 | 12.7 | 14.9 | 16.0 | 17.1 | 19.7 | 21.1 | 22.4 | 24.3 | 24.3 | 24.3 | 24.3 | 24.3 | 27.9 | 36.1 | 41.5 | 47.6 | 51.0 | 51.0 | 47.6 | 44.4 | 36.1 | 29.4 |
| 87 | 10.0 | 12.1 | 13.9 | 16.0 | 17.1 | 18.4 | 21.1 | 22.6 | 24.0 | 26.0 | 26.0 | 26.0 | 26.0 | 26.0 | 29.0 | 38.7 | 44.4 | 51.0 | 54.7 | 54.7 | 51.0 | 47.6 | 38.7 | 31.5 |
| 88 | 11.1 | 13.0 | 14.9 | 17.1 | 18.4 | 19.7 | 22.6 | 24.3 | 25.8 | 27.9 | 27.9 | 27.9 | 27.9 | 27.9 | 32.0 | 41.5 | 47.6 | 54.7 | 58.6 | 58.6 | 54.7 | 51.0 | 41.5 | 33.7 |
| 89 | 12.2 | 13.9 | 16.0 | 18.4 | 19.7 | 21.1 | 24.3 | 26.0 | 27.7 | 29.9 | 29.9 | 29.9 | 29.9 | 29.9 | 34.3 | 44.4 | 51.0 | 58.6 | 62.7 | 62.7 | 58.6 | 54.7 | 44.4 | 36.1 |
| 90 | 13.5 | 14.9 | 17.1 | 19.7 | 21.1 | 22.6 | 26.0 | 27.9 | 29.7 | 32.0 | 32.0 | 32.0 | 32.0 | 32.0 | 36.8 | 47.6 | 54.7 | 62.7 | 67.2 | 67.2 | 62.7 | 58.6 | 47.6 | 38.7 |
| 91 | 14.9 | 16.0 | 18.4 | 21.1 | 22.6 | 24.3 | 27.9 | 29.9 | 31.8 | 34.3 | 34.3 | 34.3 | 34.3 | 34.3 | 39.4 | 51.0 | 58.6 | 67.2 | 72.0 | 72.0 | 67.2 | 62.7 | 51.0 | 41.5 |
| 92 | 16.0 | 17.1 | 19.7 | 22.6 | 24.3 | 26.0 | 29.9 | 32.0 | 34.2 | 36.8 | 36.8 | 36.8 | 36.8 | 36.8 | 42.2 | 54.7 | 62.7 | 72.0 | 77.2 | 77.2 | 72.0 | 67.2 | 54.7 | 44.4 |
| 93 | 17.1 | 18.4 | 21.1 | 24.3 | 26.0 | 27.9 | 32.0 | 34.3 | 36.7 | 39.4 | 39.4 | 39.4 | 39.4 | 39.4 | 45.3 | 58.6 | 67.2 | 77.2 | 82.7 | 82.7 | 77.2 | 72.0 | 58.6 | 47.6 |
| 94 | 18.4 | 19.7 | 22.6 | 26.0 | 27.9 | 29.9 | 34.3 | 36.8 | 39.4 | 42.2 | 42.2 | 42.2 | 42.2 | 42.2 | 48.5 | 62.7 | 72.0 | 82.7 | 88.6 | 88.6 | 82.7 | 77.2 | 62.7 | 51.0 |
| 95 | 19.7 | 21.1 | 24.3 | 27.9 | 29.9 | 32.0 | 36.8 | 39.4 | 42.2 | 45.3 | 45.3 | 45.3 | 45.3 | 45.3 | 52.0 | 67.2 | 77.2 | 88.6 | 94.9 | 94.9 | 88.6 | 82.7 | 67.2 | 54.7 |
| 96 | 21.1 | 22.6 | 26.0 | 29.9 | 32.0 | 34.3 | 39.4 | 42.2 | 45.3 | 48.5 | 48.5 | 48.5 | 48.5 | 48.5 | 55.7 | 72.0 | 82.7 | 94.9 | 102 | 102 | 94.9 | 88.6 | 72.0 | 58.6 |
| 97 | 22.6 | 24.3 | 27.9 | 32.0 | 34.3 | 36.8 | 42.2 | 45.3 | 48.5 | 52.0 | 52.0 | 52.0 | 52.0 | 52.0 | 59.7 | 77.2 | 88.6 | 102 | 109 | 109 | 102 | 94.9 | 77.2 | 62.7 |
| 98 | 24.3 | 26.0 | 29.9 | 34.3 | 36.8 | 39.4 | 45.3 | 48.5 | 52.0 | 55.7 | 55.7 | 55.7 | 55.7 | 55.7 | 64.0 | 82.7 | 94.9 | 109 | 117 | 117 | 109 | 102 | 82.7 | 67.2 |
| 99 | 26.0 | 27.9 | 32.0 | 36.8 | 39.4 | 42.2 | 48.5 | 52.0 | 55.7 | 59.7 | 59.7 | 59.7 | 59.7 | 59.7 | 68.6 | 88.6 | 102 | 117 | 125 | 125 | 117 | 109 | 88.6 | 72.0 |
| 100 | 27.9 | 29.9 | 34.3 | 39.4 | 42.2 | 45.3 | 52.0 | 55.7 | 59.7 | 64.0 | 64.0 | 64.0 | 64.0 | 64.0 | 73.5 | 94.9 | 109 | 125 | 134 | 134 | 125 | 117 | 94.9 | 77.2 |
| 101 | 29.9 | 32.0 | 36.8 | 42.2 | 45.3 | 48.5 | 55.7 | 59.7 | 64.0 | 68.6 | 68.6 | 68.6 | 68.6 | 68.6 | 78.8 | 102 | 117 | 134 | 144 | 144 | 134 | 125 | 102 | 82.7 |
| 102 | 32.0 | 34.3 | 39.4 | 45.3 | 48.5 | 52.0 | 59.7 | 64.0 | 68.6 | 73.5 | 73.5 | 73.5 | 73.5 | 73.5 | 84.4 | 109 | 125 | 144 | 154 | 154 | 144 | 134 | 109 | 88.6 |
| 103 | 34.3 | 36.8 | 42.2 | 48.5 | 52.0 | 55.7 | 64.0 | 68.6 | 73.5 | 78.8 | 78.8 | 78.8 | 78.8 | 78.8 | 90.5 | 117 | 134 | 154 | 165 | 165 | 154 | 144 | 117 | 94.9 |
| 104 | 36.8 | 39.4 | 45.3 | 52.0 | 55.7 | 59.7 | 68.6 | 73.5 | 78.8 | 84.4 | 84.4 | 84.4 | 84.4 | 84.4 | 97.0 | 125 | 144 | 165 | 177 | 177 | 165 | 154 | 125 | 102 |
| 105 | 39.4 | 42.2 | 48.5 | 55.7 | 59.7 | 64.0 | 73.5 | 78.8 | 84.4 | 90.5 | 90.5 | 90.5 | 90.5 | 90.5 | 104 | 134 | 154 | 177 | 189 | 189 | 177 | 165 | 134 | 109 |
| 106 | 42.2 | 45.3 | 52.0 | 59.7 | 64.0 | 68.6 | 78.8 | 84.4 | 90.5 | 97.0 | 97.0 | 97.0 | 97.0 | 97.0 | 111 | 144 | 165 | 189 | 203 | 203 | 189 | 177 | 144 | 117 |
| 107 | 45.3 | 48.5 | 55.7 | 64.0 | 68.6 | 73.5 | 84.4 | 90.5 | 97.0 | 104 | 104 | 104 | 104 | 104 | 119 | 154 | 177 | 203 | 217 | 217 | 203 | 189 | 154 | 125 |
| 108 | 48.5 | 52.0 | 59.7 | 68.6 | 73.5 | 78.8 | 90.5 | 97.0 | 104 | 111 | 111 | 111 | 111 | 111 | 128 | 165 | 189 | 217 | 233 | 233 | 217 | 203 | 165 | 134 |
| 109 | 52.0 | 55.7 | 64.0 | 73.5 | 78.8 | 84.4 | 97.0 | 104 | 111 | 119 | 119 | 119 | 119 | 119 | 137 | 177 | 203 | 233 | 249 | 249 | 233 | 217 | 177 | 144 |
| 110 | 55.7 | 59.7 | 68.6 | 78.8 | 84.4 | 90.5 | 104 | 111 | 119 | 128 | 128 | 128 | 128 | 128 | 147 | 189 | 217 | 249 | 267 | 267 | 249 | 233 | 189 | 154 |
| 111 | 59.7 | 64.0 | 73.5 | 84.4 | 90.5 | 97.0 | 111 | 119 | 128 | 137 | 137 | 137 | 137 | 137 | 158 | 203 | 233 | 267 | 286 | 286 | 267 | 249 | 203 | 165 |
| 112 | 64.0 | 68.6 | 78.8 | 90.5 | 97.0 | 104 | 119 | 128 | 137 | 147 | 147 | 147 | 147 | 147 | 169 | 217 | 249 | 286 | 307 | 307 | 286 | 267 | 217 | 177 |
| 113 | 68.6 | 73.5 | 84.4 | 97.0 | 104 | 111 | 128 | 137 | 147 | 158 | 158 | 158 | 158 | 158 | 181 | 233 | 267 | 307 | 329 | 329 | 307 | 286 | 233 | 189 |
| 114 | 73.5 | 78.8 | 90.5 | 104 | 111 | 119 | 137 | 147 | 158 | 169 | 169 | 169 | 169 | 169 | 194 | 249 | 286 | 329 | 352 | 352 | 329 | 307 | 249 | 203 |
| 115 | 78.8 | 84.4 | 97.0 | 111 | 119 | 128 | 147 | 158 | 169 | 181 | 181 | 181 | 181 | 181 | 208 | 267 | 307 | 352 | 377 | 377 | 352 | 329 | 267 | 217 |
| 116 | 84.4 | 90.5 | 104 | 119 | 128 | 137 | 158 | 169 | 181 | 194 | 194 | 194 | 194 | 194 | 223 | 286 | 329 | 377 | 404 | 404 | 377 | 352 | 286 | 233 |
| 117 | 90.5 | 97.0 | 111 | 128 | 137 | 147 | 169 | 181 | 194 | 208 | 208 | 208 | 208 | 208 | 239 | 307 | 352 | 404 | 433 | 433 | 404 | 377 | 307 | 249 |
| 118 | 97.0 | 104 | 119 | 137 | 147 | 158 | 181 | 194 | 208 | 223 | 223 | 223 | 223 | 223 | 256 | 329 | 377 | 433 | 464 | 464 | 433 | 404 | 329 | 267 |
| 119 | 104 | 111 | 128 | 147 | 158 | 169 | 194 | 208 | 223 | 239 | 239 | 239 | 239 | 239 | 274 | 352 | 404 | 464 | 497 | 497 | 464 | 433 | 352 | 286 |

One-third octave band centre frequencies (Hz)

| SPL | 50 | 63 | 80 | 100 | 125 | 160 | 200 | 250 | 315 | 400 | 500 | 630 | 800 | 1000 | 1250 | 1600 | 2000 | 2500 | 3150 | 4000 | 5000 | 6300 | 8000 | 10000 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 120 | 111 | 119 | 137 | 158 | 169 | 181 | 208 | 223 | 239 | 256 | 256 | 256 | 256 | 256 | 294 | 377 | 433 | 497 | 533 | 533 | 497 | 464 | 377 | 307 |
| 121 | 119 | 128 | 147 | 169 | 181 | 194 | 223 | 239 | 256 | 274 | 274 | 274 | 274 | 274 | 315 | 404 | 464 | 533 | 571 | 571 | 533 | 497 | 404 | 329 |
| 122 | 128 | 137 | 158 | 181 | 194 | 208 | 239 | 256 | 274 | 294 | 294 | 294 | 294 | 294 | 338 | 433 | 497 | 571 | 611 | 611 | 571 | 533 | 433 | 352 |
| 123 | 137 | 147 | 169 | 194 | 208 | 223 | 256 | 274 | 294 | 315 | 315 | 315 | 315 | 315 | 362 | 464 | 533 | 611 | 655 | 655 | 611 | 571 | 464 | 377 |
| 124 | 147 | 158 | 181 | 208 | 223 | 239 | 274 | 294 | 315 | 338 | 338 | 338 | 338 | 338 | 388 | 497 | 571 | 655 | 702 | 702 | 655 | 611 | 497 | 404 |
| 125 | 158 | 169 | 194 | 223 | 239 | 256 | 294 | 315 | 338 | 362 | 362 | 362 | 362 | 362 | 416 | 533 | 611 | 702 | 752 | 752 | 702 | 655 | 533 | 433 |
| 126 | 169 | 181 | 208 | 239 | 256 | 274 | 315 | 338 | 362 | 388 | 388 | 388 | 388 | 388 | 446 | 571 | 655 | 752 | 806 | 806 | 752 | 702 | 571 | 464 |
| 127 | 181 | 194 | 223 | 256 | 274 | 294 | 338 | 362 | 388 | 416 | 416 | 416 | 416 | 416 | 478 | 611 | 702 | 806 | 863 | 863 | 806 | 752 | 611 | 497 |
| 128 | 194 | 208 | 239 | 274 | 294 | 315 | 362 | 388 | 416 | 446 | 446 | 446 | 446 | 446 | 512 | 655 | 752 | 863 | 925 | 925 | 863 | 806 | 655 | 533 |
| 129 | 208 | 223 | 256 | 294 | 315 | 338 | 388 | 416 | 446 | 478 | 478 | 478 | 478 | 478 | 549 | 702 | 806 | 925 | 991 | 991 | 925 | 863 | 702 | 571 |
| 130 | 223 | 239 | 274 | 315 | 338 | 362 | 416 | 446 | 478 | 512 | 512 | 512 | 512 | 512 | 588 | 752 | 863 | 991 | 1062 | 1062 | 991 | 925 | 752 | 611 |
| 131 | 239 | 256 | 294 | 338 | 362 | 388 | 446 | 478 | 512 | 549 | 549 | 549 | 549 | 549 | 630 | 806 | 925 | 1062 | 1137 | 1137 | 1062 | 991 | 806 | 655 |
| 132 | 256 | 274 | 315 | 362 | 388 | 416 | 478 | 512 | 549 | 588 | 588 | 588 | 588 | 588 | 676 | 863 | 991 | 1137 | 1219 | 1219 | 1137 | 1062 | 863 | 702 |
| 133 | 274 | 294 | 338 | 388 | 416 | 446 | 512 | 549 | 588 | 630 | 630 | 630 | 630 | 630 | 724 | 925 | 1062 | 1219 | 1306 | 1306 | 1219 | 1137 | 925 | 752 |
| 134 | 294 | 315 | 362 | 416 | 446 | 478 | 549 | 588 | 630 | 676 | 676 | 676 | 676 | 676 | 776 | 991 | 1137 | 1306 | 1399 | 1399 | 1306 | 1219 | 991 | 806 |
| 135 | 315 | 338 | 388 | 446 | 478 | 512 | 588 | 630 | 676 | 724 | 724 | 724 | 724 | 724 | 832 | 1062 | 1219 | 1399 | 1499 | 1499 | 1399 | 1306 | 1062 | 863 |
| 136 | 338 | 362 | 416 | 478 | 512 | 549 | 630 | 676 | 724 | 776 | 776 | 776 | 776 | 776 | 891 | 1137 | 1306 | 1499 | 1606 | 1606 | 1499 | 1399 | 1137 | 925 |
| 137 | 362 | 388 | 446 | 512 | 549 | 588 | 676 | 724 | 776 | 832 | 832 | 832 | 832 | 832 | 955 | 1219 | 1399 | 1606 | 1721 | 1721 | 1606 | 1499 | 1219 | 991 |
| 138 | 388 | 416 | 478 | 549 | 588 | 630 | 724 | 776 | 832 | 891 | 891 | 891 | 891 | 891 | 1024 | 1306 | 1499 | 1721 | 1844 | 1844 | 1721 | 1606 | 1306 | 1062 |
| 139 | 416 | 446 | 512 | 588 | 630 | 676 | 776 | 832 | 891 | 955 | 955 | 955 | 955 | 955 | 1098 | 1399 | 1606 | 1844 | 1975 | 1975 | 1844 | 1721 | 1399 | 1137 |
| 140 | 446 | 478 | 549 | 630 | 676 | 724 | 832 | 891 | 955 | 1024 | 1024 | 1024 | 1024 | 1024 | 1176 | 1499 | 1721 | 1975 |  |  | 1975 | 1844 | 1499 | 1219 |
| 141 | 478 | 512 | 588 | 676 | 724 | 776 | 891 | 955 | 1024 | 1098 | 1098 | 1098 | 1098 | 1098 | 1261 | 1606 | 1844 |  |  |  |  | 1975 | 1606 | 1306 |
| 142 | 512 | 549 | 630 | 724 | 776 | 832 | 955 | 1024 | 1098 | 1176 | 1176 | 1176 | 1176 | 1176 | 1351 | 1721 | 1975 |  |  |  |  |  | 1721 | 1399 |
| 143 | 549 | 588 | 676 | 776 | 832 | 891 | 1024 | 1098 | 1176 | 1261 | 1261 | 1261 | 1261 | 1261 | 1448 | 1844 |  |  |  |  |  |  | 1844 | 1499 |
| 144 | 588 | 630 | 724 | 832 | 891 | 955 | 1098 | 1176 | 1261 | 1351 | 1351 | 1351 | 1351 | 1351 | 1552 | 1975 |  |  |  |  |  |  | 1975 | 1606 |
| 145 | 630 | 676 | 776 | 891 | 955 | 1024 | 1176 | 1261 | 1351 | 1448 | 1448 | 1448 | 1448 | 1448 | 1664 |  |  |  |  |  |  |  |  | 1721 |
| 146 | 676 | 724 | 832 | 955 | 1024 | 1098 | 1261 | 1351 | 1448 | 1552 | 1552 | 1552 | 1552 | 1552 | 1783 |  |  |  |  |  |  |  |  | 1844 |
| 147 | 724 | 776 | 891 | 1024 | 1098 | 1176 | 1351 | 1448 | 1552 | 1664 | 1664 | 1664 | 1664 | 1664 | 1911 |  |  |  |  |  |  |  |  | 1975 |
| 148 | 776 | 832 | 955 | 1098 | 1176 | 1261 | 1448 | 1552 | 1664 | 1783 | 1783 | 1783 | 1783 | 1783 | 2048 |  |  |  |  |  |  |  |  |  |
| 149 | 832 | 891 | 1024 | 1176 | 1261 | 1351 | 1552 | 1664 | 1783 | 1911 | 1911 | 1911 | 1911 | 1911 |  |  |  |  |  |  |  |  |  |  |
| 150 | 891 | 955 | 1098 | 1261 | 1351 | 1448 | 1664 | 1783 | 1911 | 2048 | 2048 | 2048 | 2048 | 2048 |  |  |  |  |  |  |  |  |  |  |

### Table A4-2. Example of tone correction calculation for a turbofan engine

| ① | ② | ③ | ④ | ⑤ | ⑥ | ⑦ | ⑧ | ⑨ | ⑩ | ⑪ |
|---|---|---|---|---|---|---|---|---|---|---|
| Band (*i*) | *f* Hz | SPL dB | S dB Step 1 | 1ΔS1 dB Step 2 | SPL′ dB Step 4 | S′ dB Step 5 | $\overline{S}$ dB Step 6 | SPL″ dB Step 7 | *F* dB Step 8 | *C* dB Step 9 |
| 1 | 50 | — | — | — | — | — | — | — | — | — |
| 2 | 63 | — | — | — | — | — | — | — | — | — |
| 3 | 80 | 70 | — | — | 70 | – 8 | – 2⅓ | 70 | — | |
| 4 | 100 | 62 | – 8 | — | 62 | – 8 | + 3⅓ | 67⅔ | — | |
| 5 | 125 | (70) | +⑧ | 16 | 71 | + 9 | + 6⅔ | 71 | — | |
| 6 | 160 | 80 | +10 | 2 | 80 | + 9 | + 2⅔ | 77⅔ | 2⅓ | 0.29 |
| 7 | 200 | 82 | +② | 8 | 82 | +2 | – 1⅓ | 80⅓ | 1⅔ | 0.06 |
| 8 | 250 | (83) | +1 | 1 | 79 | – 3 | – 1⅓ | 79 | 4 | 0.61 |
| 9 | 315 | 76 | –⑦ | 8 | 76 | – 3 | + ⅓ | 77⅔ | — | |
| 10 | 400 | (80) | +④ | 11 | 78 | + 2 | + 1 | 78 | 2 | 0.17 |
| 11 | 500 | 80 | 0 | 4 | 80 | + 2 | 0 | 79 | — | |
| 12 | 630 | 79 | – 1 | 1 | 79 | – 1 | 0 | 79 | — | |
| 13 | 800 | 78 | – 1 | 0 | 78 | – 1 | – ⅓ | 79 | — | |
| 14 | 1 000 | 80 | +2 | 3 | 80 | + 2 | – ⅔ | 78⅔ | | |
| 15 | 1 250 | 78 | – 2 | 4 | 78 | – 2 | – ⅓ | 78 | — | |
| 16 | 1 600 | 76 | – 2 | 0 | 76 | – 2 | + ⅓ | 77⅔ | — | |
| 17 | 2 000 | 79 | +3 | 5 | 79 | + 3 | + 1 | 78 | | |
| 18 | 2 500 | (85) | +6 | 3 | 79 | 0 | – ⅓ | 79 | 6 | $\boxed{2}$ |
| 19 | 3 150 | 79 | –⑥ | 12 | 79 | 0 | – 2⅔ | 78⅔ | — | |
| 20 | 4 000 | 78 | – 1 | 5 | 78 | – 1 | – 6⅓ | 76 | 2 | 0.33 |
| 21 | 5 000 | 71 | –⑦ | 6 | 71 | – 7 | – 8 | 69⅔ | — | |
| 22 | 6 300 | 60 | –11 | 4 | 60 | –11 | – 8⅔ | 61⅔ | — | |
| 23 | 8 000 | 54 | – 6 | 5 | 54 | – 6 | – 8 | 53 | | |
| 24 | 10 000 | 45 | – 9 | 3 | 45 | – 9 | — | 45 | — | |
| | | | | | | – 9 | | | | |

| | |
|---|---|
| Step 1 | ③(*i*) – ③(*i* – 1) |
| Step 2 | \|④(*i*) – ④(*i* – 1)\| |
| Step 3 | See 4.3.1 of Appendix 2 of Annex 16, Volume I |
| Step 4 | Same as above |
| Step 5 | ⑥(*i*) – ⑥(*i* – 1) |

| | |
|---|---|
| Step 6 | [⑦(*i*) + ⑦(*i* + 1) + + ⑦(*i* + 2)] ÷ 3 |
| Step 7 | ⑨(*i* – 1) + ⑧(*i* – 1) |
| Step 8 | ③(*i*) – ⑨(*i*) |
| Step 9 | See Table 2-2 of Appendix 2 of Annex 16, Volume I |

*Note.— Steps 5 and 6 may be eliminated in the calculations if desired. In this case in the example shown in Table A4-2, columns ⑦ and ⑧ should be removed and existings columns ⑨ , ⑩ and ⑪ become ⑦ , ⑧ and ⑨ covering new steps 5, 6 and 7 respectively. The existing steps 5, 6, 7, 8 and 9 in 4.3.1 are then replaced by:*

*STEP 5 [ ⑥ (i – 1) + ⑥ i + ⑥ (i + 1)] ÷ 3*
*STEP 6 ③ ( i ) – ⑦ ( i ) if > 0*
*STEP 7 See Table 2-2 of Appendix 2 of Annex 16, Volume I.*

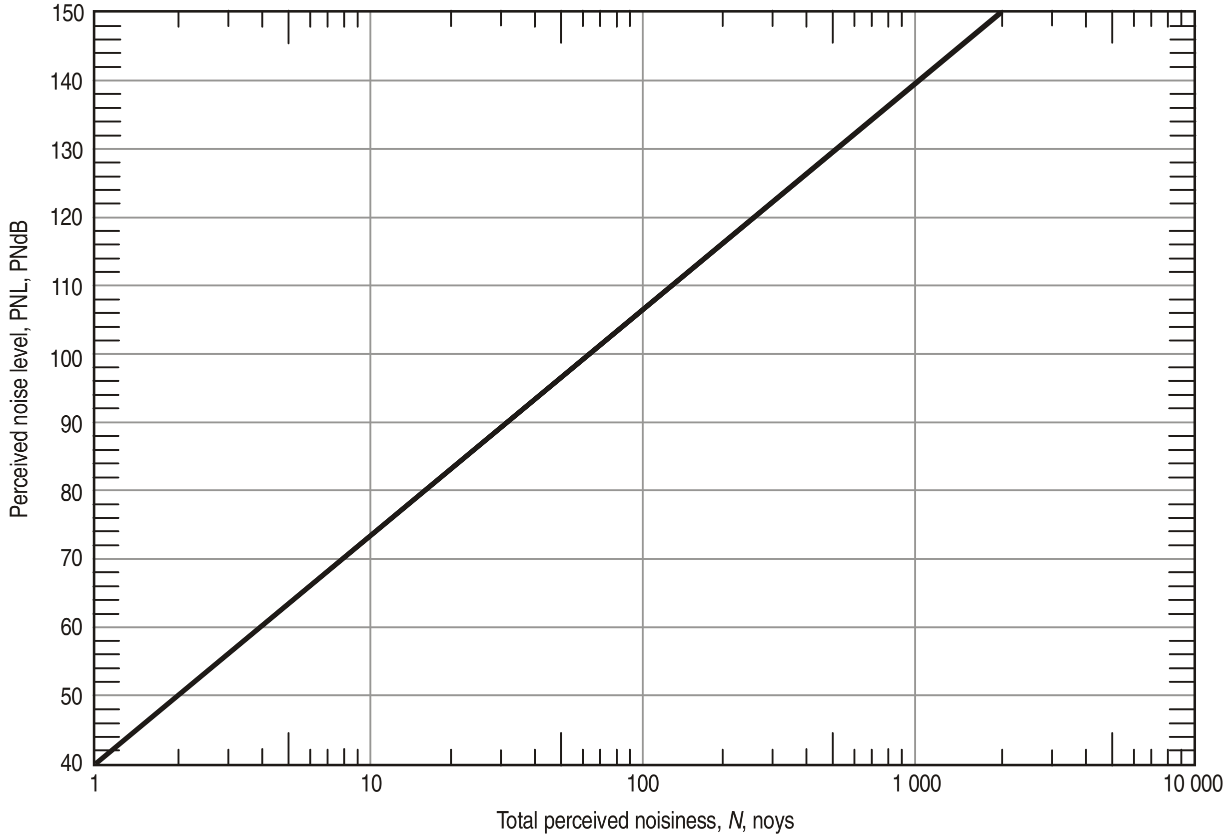

**Figure A4-1. Perceived noise level as a function of total perceived noisiness**

# Appendix 5

# WORKED EXAMPLE OF CALCULATION OF REFERENCE FLYOVER HEIGHT AND REFERENCE CONDITIONS FOR SOURCE NOISE ADJUSTMENTS FOR CERTIFICATION OF LIGHT PROPELLER-DRIVEN AEROPLANES TO CHAPTER 10 OF ANNEX 16, VOLUME I

## 1. INTRODUCTION

The reference flyover height for an aeroplane certificated to Chapter 10 of Annex 16 — *Environmental Protection*, Volume I — *Aircraft Noise* is defined at a point which is 2 500 m from the start of roll beneath a reference flight path determined according to the take-off reference procedure described in 10.5.2 of Annex 16, Volume I. An expression for the reference flyover height in terms of commonly approved performance data and an example of how such an expression may be worked are presented in this appendix. The relationship between this reference height and the conditions to which source noise corrections are to be made is also explained.

## 2. TAKE-OFF REFERENCE PROCEDURE

2.1 The take-of reference procedure for an aeroplane certificated to Chapter 10 is defined under sea level, International Standard Atmosphere (ISA) conditions, at maximum take-off mass for which noise certification is requested in 10.5.2 of Chapter 10 of Annex 16, Volume I. The procedure is described in two phases.

2.2 The first phase commences at "brakes release" and continues to the point where the aircraft reaches a height of 15 m (or 50 ft) above the runway (the point of interception of a vertical line passing through this point with a horizontal plane 15 m (or 50 ft) below is often referred to as "reference zero").

2.3 The second phase commences at the end of the first phase and assumes the aeroplane is in normal climb configuration with landing gear up and flap setting normal for "second segment" climb.

2.4 It should be noted that in this respect, the reference "acoustic" flight path ignores the "first segment" part of the flight path, during which the aircraft accelerates to normal climb speed and, where appropriate, landing gear and flaps are retracted.

## 3. EXPRESSION FOR REFERENCE HEIGHT

3.1 The reference flyover height is defined according to the take-off reference flight path at a point 2 500 m from the start of roll for an aeroplane taking off from a paved, level runway under the following conditions:

— sea level atmospheric pressure of 1 013.25 hPa;

— ambient air temperature of 15°C, i.e. ISA

— relative humidity of 70 per cent; and

— zero wind.

3.2 This height can be defined in terms of the approved take-off and climb performance figures for the conditions described above as follows:

$$H_R = (2\ 500 - D_{15}) \times \tan\left(\left[\sin^{-1}\left(\frac{RC}{V_y}\right)\right] + 15\right) \qquad \textit{Equation (1)}$$

where:

$H_R$ is the reference height in metres;

$D_{15}$ is the sea level, ISA take-off distance in metres to a height of 15 m at the maximum certificated take-off mass and maximum certificated take-off power;

*RC* is the sea level, ISA best rate of climb (m/sec) at the maximum certificated take-off mass and the maximum power and rpm that can be continuously delivered by the engine(s) during this second phase; and

$V_y$ is the best rate of climb speed (m/sec) corresponding to *RC*.

3.3 The performance data in many flight manuals is often presented in terms of non-SI units. Typically the take-off distance (expressed in feet) is given to a height of 50 ft, the rate of climb is expressed in feet per minute (ft/min) and the airspeed in knots (kt). In such instances, the expression for reference flyover height, $H_R$ ft, becomes:

$$H_R = (8\ 203 - D_{50}) \times \tan\left[\sin^{-1}\left(\frac{RC}{101.4V_y}\right)\right] + 50 \qquad \textit{Equation (2)}$$

where:

$D_{50}$ is the sea level, ISA take-off distance in feet to a height of 50 ft;

*RC* is the sea level, ISA best rate of climb (ft/min); and

$V_y$ is the best rate of climb speed (kt).

3.4 The performance figures can normally be found in the performance section of an aircraft's flight manual or pilot's handbook. Note that for certain categories of aircraft, a safety factor may be applied to the take-off and climb performance parameters presented in the flight manual. In the case of multi-engined aircraft, it may be assumed that one engine is inoperative during part of Phase 1 and during Phase 2. For the purpose of calculating the "acoustic" reference flight path, the take-off distance and rate of climb should be determined for all engines operating by using gross, i.e. unfactored, data.

3.5 In addition, the best rate of climb speed, $V_y$, used in Equation (2) is defined as the true airspeed (TAS). However in the flight manual, speed is normally presented in terms of indicated airspeed (IAS). This should be corrected to the calibrated airspeed (CAS) by applying the relevant position error and instrument corrections for the airspeed indicator. These corrections can also be found in the manual. For an ISA day at sea level, the TAS is then equal to the CAS.

## 4. REFERENCE CONDITIONS FOR SOURCE NOISE ADJUSTMENTS

4.1 Paragraphs 5.2.1 c and 5.2.1 d of Appendix 6 of the Annex 16, Volume I describe how corrections for differences in source noise between test and reference conditions shall be made.

4.2 The reference helical tip Mach number and engine power are defined for the reference conditions above the measurement point, i.e. the reference atmospheric conditions at the reference height, $H_R$.

4.3 The reference temperature at the reference height ($H_R$) is calculated under ISA conditions, i.e. for an ambient sea level temperature of 15°C and assuming a standard temperature lapse rate of 1.98°C per 1 000 ft. The reference temperature, $T_R$ °C, can be defined as:

$$T_R = 15 - 1.98\left(\frac{H_R}{1\ 000}\right) \qquad \textit{Equation (3)}$$

4.4 The reference atmospheric pressure, $P_R$ hPa, is similarly calculated at the reference height ($H_R$) for a standard sea level pressure of 1 013.25 hPa, assuming a standard pressure lapse rate of:

$$P_R = 1\ 013.25\left[1 - (6.7862 \times 10^{-6} H_R)\right]^{5.325} \qquad \textit{Equation (4)}$$

## 5. WORKED EXAMPLE FOR THE CALCULATION OF REFERENCE FLYOVER HEIGHT AND THE ASSOCIATED REFERENCE ATMOSPHERIC CONDITIONS

### 5.1 Example of reference flyover height calculation

5.1.1 In Table A5-1 extracts are presented from the performance section of a flight manual for a typical light, single engined propeller-driven aeroplane.

5.1.2 The introduction contains a statement to the effect that the information is derived from "measured flight test data" and includes "no additional factors".

5.1.3 The sea level, ISA take-off distance in feet to a height of 50 ft at the reference conditions cited in Chapter 10 of Annex 16, Volume I can be read from the table of take-off distances presented for a paved runway at the maximum certificated take-off weight of 1 920 lb. Thus $D_{50}$ is 1 370 ft.

5.1.4 The rate of climb (*RC*) at the reference conditions can similarly be read from the rate of climb (*RC*) table. Thus *RC* is 1 000 ft/min.

5.1.5 The climb speed associated with the rate of climb figures is given as 80 kIAS. The corresponding true airspeed at the reference conditions cited in Chapter 10 of Annex 16, Volume I is equal to the indicated airspeed (IAS) corrected according to the airspeed calibration table at the appropriate flap setting of 0°. Thus $V_y$ is 81 kTAS.

5.1.6 Entering these parameters into the expression for reference height (ft) given in Equation (2) gives:

$$H_R = (8\ 203 + 1\ 370) \times \tan\left[\sin^{-1}(1\ 000/101.4 \times 81)\right] + 50$$

and so $H_R = 888\ ft$.

## 5.2 Example of calculation of reference atmospheric conditions

5.2.1 The reference temperature at the reference height, $H_R$, is given by Equation (3):

$$T_R = 15 - 1.98\left(\frac{88}{1\ 000}\right)$$

and so $T_R$ = 13.24°C.

5.2.2 The reference pressure at the reference height is given by Equation (4):

$$P_R = 1\ 013.25\left[1 - (6.7862 \times 10^{-6} \times 888)\right]^{5.325}$$

and so $P_R = 981\ hPa$.

**Table A5-1. Example of flight manual performance section**

## SECTION 5. PERFORMANCE

### 1. INTRODUCTION

The data processed in this section enables flight planning to be carried out for flights between airfields with various altitudes, temperatures and field lengths. The information is derived from measured flight test data using CAA-approved methods and factors to cover all the conditions shown. The data assumes average pilot skill and an aircraft engine and propeller in good condition.

**No additional factors are included** and it is the pilot's responsibility to apply safety factors which must not be less than those…

### 6. AIRSPEED CALIBRATION

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **0°** | **KIAS** | — | 60 | 70 | **80** | 90 | 100 | 110 | 120 | 130 | 180 |
| | **flap** | KCAS | — | 61 | 71 | **81** | 91 | 101 | 111 | 121 | 131 | 181 |
| | 15° | KIAS | 50 | 60 | 70 | 80 | 85 | — | — | — | — | — |
| | flap | KCAS | 51 | 61 | 71 | 81 | 86 | — | — | — | — | — |
| | 35° | KIAS | 50 | 60 | 70 | 80 | 85 | — | — | — | — | — |
| | flap | KCAS | 50 | 59 | 69 | 79 | 84 | — | — | — | — | — |

### TAKE-OFF DISTANCE — PAVED RUNWAY (1) — Conditions

Flaps — 15°
Weight — 1 920 lbs ”
Power — Full throttle

Rotation speed — 53 KIAS
Speed at 50 ft — 65 KIAS

| | ISA –20°C | | ISA –10°C | | **ISA** | | ISA +10°C | | ISA +20°C | | ISA +30°C | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **AIR-FIELD HEIGHT FT** | GMD Roll | Total to 50 ft | GMD Roll | Total to 50 ft | GMD Roll | **Total to 50 ft** | GMD Roll | Total to 50 ft | GMD Roll | Total to 50 ft | GMD Roll | Total to 50 ft |
| **Sea level** | 530 | 1 230 | 565 | 1 290 | 600 | **1 370** | 700 | 1 580 | 750 | 1 715 | 840 | 1 900 |
| 5 000 | 1 045 | 2 835 | 1 065 | 2 435 | 1 090 | 2 580 | 1 170 | 2 670 | 1 295 | 2 840 | 1 290 | 2 905 |
| 10 000 | 1 0465 | 3 335 | 1 490 | 3 390 | 1 510 | 3 435 | 1 575 | 3 560 | 1 610 | 3 695 | 1 670 | 3 790 |

### RATE OF CLIMB — Conditions

Flaps UP
Weight — 1 920 lbs

Full throttle
Speed — 80 KIAS

| **PRESSURE ALTITUDE FT** | Rate of climb Feet/Minute | | | |
|---|---|---|---|---|
| | ISA –20°C | ISA | ISA +10°C | ISA +20°C |
| **Sea level** | 1 035 | **1 000** | 915 | 825 |
| 1 000 | 980 | 945 | 860 | 770 |
| 2 000 | 925 | 890 | 805 | 720 |
| 3 000 | 870 | 830 | 750 | 665 |
| 4 000 | 815 | 775 | 695 | 610 |
| 5 000 | 765 | 720 | 640 | 560 |
| 6 000 | 700 | 665 | 585 | 505 |
| 7 000 | 635 | 605 | 560 | 450 |
| 8 000 | 570 | 550 | 475 | 395 |
| 9 000 | 495 | 480 | 410 | 335 |
| 10 000 | 415 | 405 | 335 | 270 |

# Appendix 6

## NOISE DATA CORRECTIONS FOR TESTS AT HIGH ALTITUDE TEST SITES

### 1. INTRODUCTION

Jet noise generation is somewhat suppressed at higher altitudes due to the difference in the engine jet velocity and jet velocity shear effects resulting from the change in air density. The use of a high altitude test site for the noise test of an aeroplane model that is primarily jet noise dominated should include making the following corrections. These jet source noise corrections are in addition to the standard pistonphone barometric pressure correction of about 0.1 dB/100 m (0.3 dB/1 000 ft) which is normally used for test sites not approximately at sea level. The jet source noise corrections are applicable to tests conducted at sites at or above 366 m (1 200 ft) mean sea level (MSL).

### 2. JET NOISE SOURCE CORRECTION

Flight test site locations at or above 366 m (1 200 ft) MSL, but not above 1 219 m (4 000 ft) MSL, may be approved provided the criteria (Figure A6-1 in 2.1 of this appendix) are met and the source noise corrections (2.2 of this appendix) are applied. Alternative criteria or corrections require the approval of the certificating authority.

### 2.1 Criteria

Jet source noise altitude corrections from 2.2 of this appendix are required for each one-half second spectrum when using the integrated procedure and for the Maximum Tone Corrected Perceived Noise Level (PNLTM) spectrum when using the simplified procedure (see 9.3 and 9.4 of Appendix 2 of Annex 16 — *Environmental Protection*, Volume I — *Aircraft Noise*), and are to be applied in accordance with the criteria described in Figure A6-1.

### 2.2 Correction Procedure

An acceptable jet source noise correction is as follows:

a) correct each half second spectrum (or PNLTM one-half second spectrum, as appropriate) in accordance with the criteria of 2.1 of this appendix by using the following equation:

$$\Delta SPL = [10 \log (d_R/d_T) + 50 \log (c_T/c_R) + 10k \log (u_R/u_T)] [F1] [F2]$$

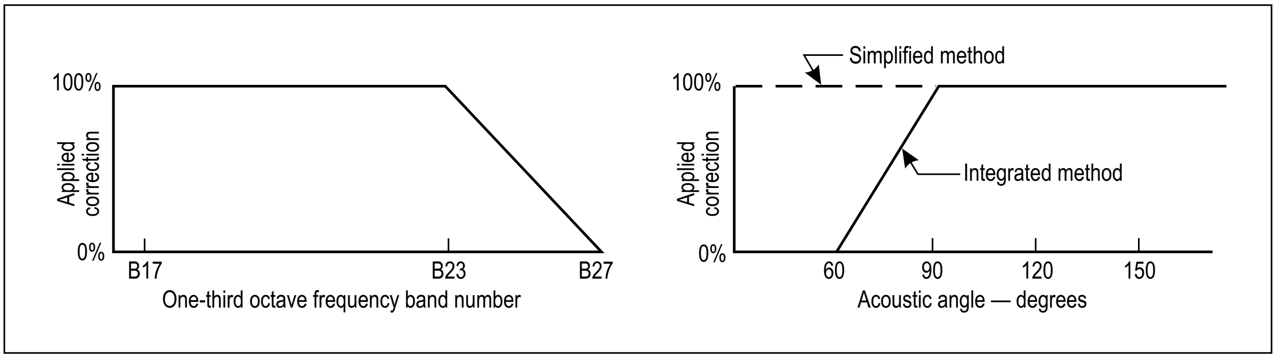

**Figure A6-1. Criteria for jet noise source correction**

where:

Subscript $T$ denotes conditions at the actual aeroplane test altitude above MSL under standard atmospheric conditions, i.e. ISA+10°C and 70 per cent relative humidity;

Subscript $R$ denotes conditions at the aeroplane reference altitude above MSL (i.e. aeroplane test altitude above MSL minus the test site altitude) under standard atmospheric conditions, i.e. ISA+10°C and 70 per cent relative humidity;

*SPL* denotes sound pressure level;

$d_R$ is the density for standard atmosphere at the aeroplane reference altitude in kg/m$^3$ (lb/ft$^3$);

$d_T$ is the density for standard atmosphere at the aeroplane test altitude in kg/m$^3$ (lb/ft$^3$);

$c_R$ is the speed of sound corresponding to the absolute temperature for standard atmosphere at aeroplane reference altitude in m/s (ft/s);

$c_T$ is the speed of sound corresponding to the absolute temperature for standard atmosphere at aeroplane test altitude in m/s (ft/s);

$k = 8$, unless an otherwise empirically derived value is substantiated;

$u = (v_e - v_a)$ is the equivalent relative jet velocity in m/s (ft/s)

where:

$v_e$ is the equivalent jet velocity as defined in SAE ARP 876D, Appendix C (January 1994) and obtained from the engine cycle deck in m/s (ft/s); and

$v_a$ is the aircraft velocity in m/s (ft/s).

$u_R$ is the equivalent relative jet velocity in m/s (ft/s) where $v_e$ is determined at $\mathrm{N1C_{TEST}}$ for standard atmosphere at the aeroplane reference altitude;

$u_T$ is the equivalent relative jet velocity in m/s (ft/s) where $v_e$ is determined at $\mathrm{N1C_{TEST}}$ for standard atmosphere at the aeroplane test altitude;

*N1C* is the corrected engine rpm $N_1/(\sqrt{\theta_{T_2}})$ ;

*F1* is a factor corresponding to the percentage of applied correction related to acoustic angle in Figure A6-1 (values range from 0.00 to 1.00); and

*F2* is a factor corresponding to the percentage of applied correction related to the one-third octave band in Figure A6-1 (values range from 0.00 to 1.00);

b) for each one-third octave band SPL, arithmetically add the altitude jet noise correction in 2.2 a) to the measured SPLs to obtain the altitude jet source noise corrected SPLs for the derivation of Perceived Noise Level described in 4.1.3 a) of Appendix 2 of Annex 16, Volume I; and

c) the altitude correction is to be applied to all measured test data including approach conditions (unless it can be substantiated that the jet noise during approach does not contribute significantly to the total aircraft noise).

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# Appendix 7

# TECHNICAL BACKGROUND INFORMATION ON THE GUIDELINES FOR THE NOISE CERTIFICATION OF TILT-ROTOR AIRCRAFT

## 1. INTRODUCTION

The guidelines for the noise certification of tilt-rotor aircraft presented in Attachment F of Annex 16 — *Environmental Protection*, Volume I — *Aircraft Noise* have been developed by the CAEP Tilt-Rotor Task Group specifically for the noise certification of the Bell/Agusta 609, the first example of a civil tilt-rotor aircraft. It is also intended that these guidelines be used as the basis for noise certification of subsequent tilt-rotor aircraft. The explanatory material in this appendix is intended to give an insight as to how the guidelines have been developed, particularly with regard to their application to the Bell/Agusta 609. It is hoped that the information may serve as a useful guide to the development of the guidelines to be used for other tilt-rotor aircraft and the possible eventual adoption of these guidelines as a Standard in Annex 16.

## 2. GENERAL TECHNICAL INFORMATION

### 2.1 Aeroplane mode, helicopter mode

2.1.1 The term "aeroplane mode" is used when the rotors are orientated with their axis of rotation substantially horizontal (i.e. engine nacelle angle near 0 degrees on the "down stops". See below).

2.1.2 The term "helicopter mode" is used when the rotors are orientated with their axis of rotation substantially vertical (nacelle angle around 90 degrees). In the guidelines in Attachment F of Annex 16, Volume I, the condition is referred to as the "VTOL/Conversion mode", which is the term used in the Airworthiness Standards in development for the Bell/Agusta 609. VTOL stands for Vertical Take-Off and Landing.

### 2.2 Nacelle angle

The "nacelle angle" is defined as the angle between the rotor shaft centreline and the longitudinal axis of the aircraft fuselage. The nacelle is normally perpendicular to the plane of rotation of the rotor.

### 2.3 Gates

2.3.1 In the design of the Bell/Agusta 609, there are a number of preferred nacelle angle positions called "gates". These are default positions that will normally be used for normal operation of the aircraft. The nacelle angle is controlled by a self-centring switch. When the nacelle angle is 0 degrees (aeroplane mode) and the pilot hits the switch upwards, the nacelles will automatically turn to a position of approximately 60 degrees, where it will stop. Hitting the switch once more will make the nacelle turn to a position of approximately 75 degrees. Above 75 degrees the nacelle angle can be set to any angle up to approximately 95 degrees by holding the switch up (or down to go back).

2.3.2 The "gate" concept is expected to be typical for all future tilt-rotors, although the number and position of the gates may vary. The gates play an important role in the airworthiness requirements, where they are defined as "authorized fixed operation points in the VTOL/conversion mode". When the aircraft is flying in the aeroplane mode, the nacelle angle will be in line with the longitudinal axis of the aircraft. In this case the angle is fixed by using the so-called "down stop"

### 2.4 Rotor RPM

The design of the Bell/Agusta 609 and most likely future designs of tilt-rotors will have at least two possible Rotor

RPMs: one for the helicopter mode and another (lower) RPM for the aeroplane cruising mode. The lower RPM can only be used when the nacelles are on the down stop. Before leaving the down stop, the RPM must be set to the higher value for the tilt-rotor to be able to hover.

### 2.5 Form and extent of the guideline

2.5.1 It is considered that at this moment there is not enough experience with tilt-rotor aircraft to justify adoption of firm Standards. Therefore the guidance material has been developed in "green pages" in the form of Attachment F for Annex 16, Volume I, much like the guidelines for noise certification of propeller-driven STOL aeroplanes that are already in the green pages in Attachment B of Annex 16, Volume I. It was deemed desirable to give the same level of detail as is found in comparable chapters of Annex 16, Volume I, including information on date of applicability to promote a uniform application of the guidelines.

2.5.2 After careful deliberations, it has been concluded that the current Standards of Chapter 8 of Annex 16, Volume I were a good basis for the guidelines in Attachment F and that the differences between the guidelines and Chapter 8 should be minimized.

- The noise from tilt-rotors will be most prominent during departure and approach. In these situations tilt-rotors will normally operate in or near the "helicopter mode".
- In the development of the guidelines, the noise of the Bell XV15 tilt-rotor aircraft (which serves as a prototype for the Bell/Agusta 609) has been observed. It was concluded that the character of the noise of this aircraft was much like that of a normal helicopter.
- In horizontal flyover, the "helicopter mode" will normally be the noisiest configuration.
- The proposed guidelines are confined to tilt-rotors that can only take off vertically, excluding those with STOL characteristics. They will operate much like normal helicopters, with relatively steep take-off and approach paths.
- The level of available noise abatement technology for tilt-rotors is considered to be the same as for helicopters.
- Tilt-rotor operations will often mix with helicopter operations from the same heliport. Therefore there will be a desire to compare the noise from tilt-rotors and helicopters.

### 2.6 Transition phase noise

2.6.1 One item of strong interest is the transition from one nacelle angle to the other which may be associated with particular noise generation mechanisms. For example, when one considers the tilt-rotor transition from aeroplane mode to helicopter mode while decelerating, there is a phase in which the component of the speed vector that is perpendicular to the rotor changes from "top to bottom" to "bottom to top". It would be conceivable that sometime during the transition phase, blade vortices would be ingested or another non-stationary effect would create additional noise.

2.6.2 A number of overflights of the Bell XV15 were listened to, one of which was especially set up to study the noise during transition. In this run, the tilt-rotor (Bell XV15) passed overhead at 500 ft while transitioning from aeroplane to helicopter mode. No special phenomena were noticed during this flight. In addition, during the other runs, in which there were demonstrations of hover, hover turns, sideward flight, take-off, level flyovers at various speeds/nacelle angles combinations and approaches at 6 and 9 degrees, no particularities were heard, other than normal Blade Vortex Interaction noise during both the 6 and 9 degree approaches. During the procedures to set the aircraft up for the various runs, several transitions were made from helicopter to aeroplane mode and back, which were listened to from different positions relative to the aircraft. No particular noise was heard.

2.6.3 Based on this experience and the arguments stated as follows, it has been decided not to attempt to define a special test point aimed at catching transition noise of tilt-rotors.

The arguments for this are:

- Experienced observers from industry claim they never noticed any particular noise phenomena associated with the transitional phase. This was backed up by the specific observations of the Bell XV15 referred to above.
- The conversion rate is relatively slow, which means that during the whole conversion process, the flow field also changes very slowly.

— If there would be a transitional noise, it would probably be related to some form of Blade Vortex Interaction. This phenomenon is covered under the approach procedure and it might be hard to justify adding a measurement point to get some additional information.

— Defining a reproducible and practicable procedure to catch the transition noise which nobody has ever noticed is virtually impossible.

— If in the future there is a design that has clear transitional noise characteristics, the effect could be studied and, if deemed necessary, an amendment to the guidelines could be proposed.

## 3. COMMENTS TO INDIVIDUAL SECTIONS OF THE PROPOSED GUIDELINE

Following the order of appearance in the proposed guideline the following comments are offered:

### 3.1 Definition (re Note 1 of Attachment F)

The proposed definition was proposed by the International Coordinating Council of Aerospace Industries Association (ICCAIA). It focuses on the fundamental difference between tilt-rotors and other aircraft.

### 3.2 Applicability (re Note 2 and 1 of Attachment F)

An applicability section has been added to promote uniform application of the guidelines. The reference to derived versions means that no measurements are required on aircraft that are quieter than their parents due to the definition of derived versions in Annex 16, Volume I. The date chosen is the date when this section of the guidelines was discussed.

### 3.3 Noise Evaluation Measure (re Section 2 of Attachment F)

3.3.1 In view of the commonality with helicopters, the same units used in Chapter 8 of Annex 16. Volume I are proposed. It is proposed that no new appendix for tilt-rotors be created, since the current Appendix 2 in Annex 16, Volume I is considered to be appropriate. For land use planning purposes, it is proposed that additional data be made available. Which data should be provided is left to be determined between the authority and the applicant, since the needs of different authorities in this respect may differ.

3.3.2 At this moment, the intention of this section of the guidelines is to only require data that can be gathered through additional analysis of the data that have already been measured for certification purposes. It is hoped that the Society of Automotive Engineers (SAE) will investigate further the data requirements for Land Use Planning. Since the information needed for Land Use Planning can be of such detail that it is commercially sensitive, it is not the intent to make such information available to the public.

### 3.4 Noise Measurement Reference Points (re Section 3 of Attachment F)

In view of the desired commonality with helicopters, the same noise measurement reference points used for Chapter 8 of Annex 16, Volume I are proposed.

### 3.5 Maximum Noise Levels and trade-offs. (re Sections 4 and 5 of Attachment F)

In view of the desired commonality with helicopters, it is considered that the current Chapter 8 (of Annex 16, Volume I) limits and trade-offs serve as a good starting point for use in the guidelines. In the helicopter mode, both the lift technology and operating environment are similar to those of a helicopter. If the technology requires higher limits or makes possible lower limits, this should be considered by the individual authority when using the guidelines in a particular case. For the flyover case, there is only a limit specified for the helicopter mode, since this is normally the noisiest configuration and also the configuration most likely to be used when flying the circuit pattern.

### 3.6 Noise Certification reference procedures (re Section 6 of Attachment F)

The capability to change the nacelle angle and the two different, possibly more RPMs require some additions to the current helicopter reference procedures in Chapter 8 (of Annex 16, Volume I).

### 3.7 RPM

In the guidelines, the RPM required is linked to the corresponding flight condition. This means that for take-off, approach and flyover in the helicopter mode, the higher RPM will have to be used, while for the flyover in aeroplane mode, the lower RPM has to be used.

### 3.8 Nacelle angle

3.8.1 In *take-off*, the choice of the nacelle angle is left to the applicant. This is in line with the philosophy of Annex 16, Volume I, where the choice of the configuration is left to the applicant. It is also in line with the requirement in Chapter 8 to use the aircraft best rate of climb speed, *Vy*, since the applicant will normally choose the nacelle angle that is close to the nacelle angle that corresponds to the overall best rate of climb. (Note that for each nacelle angle, there is a speed that gives the best rate of climb, which is normally not the same numerical value for different nacelle angles. There will be one nacelle angle that gives the highest overall rate of climb, but this is usually not an angle that corresponds to a "gate".)

3.8.2 In the case of *flyover in helicopter mode*, the definition of the nacelle angle to be used was one of the more difficult problems. Initially it was proposed to use a nacelle angle of 90 degrees, comparable to a helicopter. This was however unsatisfactory because a tilt-rotor will normally not fly at this angle at the high speed required for noise certification. Normally the rotor will be tilted to get more forward thrust without tilting the fuselage forward and to do this, a nacelle angle of approximately 80 degrees is selected. It was agreed that this unique capability of the tilt-rotor should be incorporated in the reference procedure. On the other hand the requirement should prevent the applicant from choosing a nacelle angle that would be close to 0 degrees since this would give unrealistically low noise figures. (Note that tilting the rotor will reduce the advancing blade tip mach number). After long deliberations, a satisfactory solution was found: For a tilt-rotor there will normally be a nacelle angle below which hover is no longer possible and for which flight with zero airspeed is not permitted. It was decided to fix the nacelle angle for the flyover in helicopter mode to the gate closest to that angle.

3.8.3 In the *flyover in aeroplane mode*, the nacelle angle is defined as on the down stop, the position that will normally be used for cruise and high speeds. Two conditions are measured:

a) one is with the high RPM and the same speed as used in the helicopter mode flyover. This condition is intended to make it possible to make comparisons between the helicopter mode and aeroplane mode flyover; and

b) the other condition is with the cruise RPM and speed *Vmcp* or *Vmo* (as defined in Note 1 of 6.3 e) of Attachment F of Annex 16, Volume I), which is intended to represent a worst case cruise condition.

3.8.4 For the *approach reference configuration*, the nacelle angle for maximum approach noise should be used. This is in line with the philosophy in Chapter 8 and other parts of Annex 16, Volume I that require the noisiest configuration for approach. This will normally require testing several different nacelle angles in order to determine which is noisiest.

3.8.5 In the tilt-rotor aircraft design, the flap angle varies with airspeed so the pilot may manually set flaps or may use auto flap control in order to reduce the pilot's workload. In this latter case, the flap angle for noise certification will be the flap angle that is normal for the approach configuration and approach condition flown. For a design with pilot-controlled flap angle, the applicant should use the flap angle designated for approach and will have to prove that the noisiest configuration is used for noise certification.

### 3.9 Test procedures
### (re Section 7 of Attachment F)

The test procedures are the same as in Chapter 8 of Annex 16, Volume I. Note that this means that as a minimum, all data are taken and evaluated at 1.2 m, including data taken for Land Use Planning purposes. This is proposed in order to maintain commonality with Chapter 8 numbers and to reduce costs for the applicant. If, for Land Use Planning or other purposes, the gathering of data at other microphone positions (i.e. at ground plane) were desired, this would of course be allowed but would have to be agreed between applicant and certificating authority.

# Appendix 8

# RE-CERTIFICATION OF AN AEROPLANE

## 1. INTRODUCTION

1.1 Re-certification is defined as the "certification of an aircraft, with or without revision to noise levels, to a Standard different to that which it had been originally certified". The re-certification of helicopters and light propeller-driven aeroplanes to a different Standard from that to which they were originally certificated is not considered.

1.2 In the case of an aeroplane being re-certificated to the Standard of Chapter 4 in Annex 16 — *Environmental Protection*, Volume I — *Aircraft Noise*, noise re-certification should be granted on the basis that the evidence used to determine compliance is as satisfactory as the evidence expected of a new type design. In this respect the date used by a certificating authority to determine the re-certification basis should be the date of acceptance of the first application for re-certification.

1.3 Section 2 of this appendix is concerned with the assessment of existing approved noise levels associated with applications for the re-certification of an aeroplane to Chapter 4. Section 3 includes guidelines for the re-certification to Chapter 4 of aeroplanes specially "modified" in order to achieve compliance with Chapter 4. The appropriate process for determining the compliance of a re-certificated aircraft with a new Standard should be determined by the aircraft's certified noise levels and the associated substantiation document(s). A flow chart describing the process for the re-certification of subsonic jet aeroplanes from Chapter 3 to Chapter 4 is presented in Figure A8-1.

1.4 In the application of these re-certification guidelines, existing arrangements between certificating authorities should be respected. It is expected that bilateral arrangements will facilitate the mutual recognition between authorities of approvals granted in accordance with the guidelines recommended in this appendix.

## 2. ASSESSMENT CRITERIA

### 2.1 General

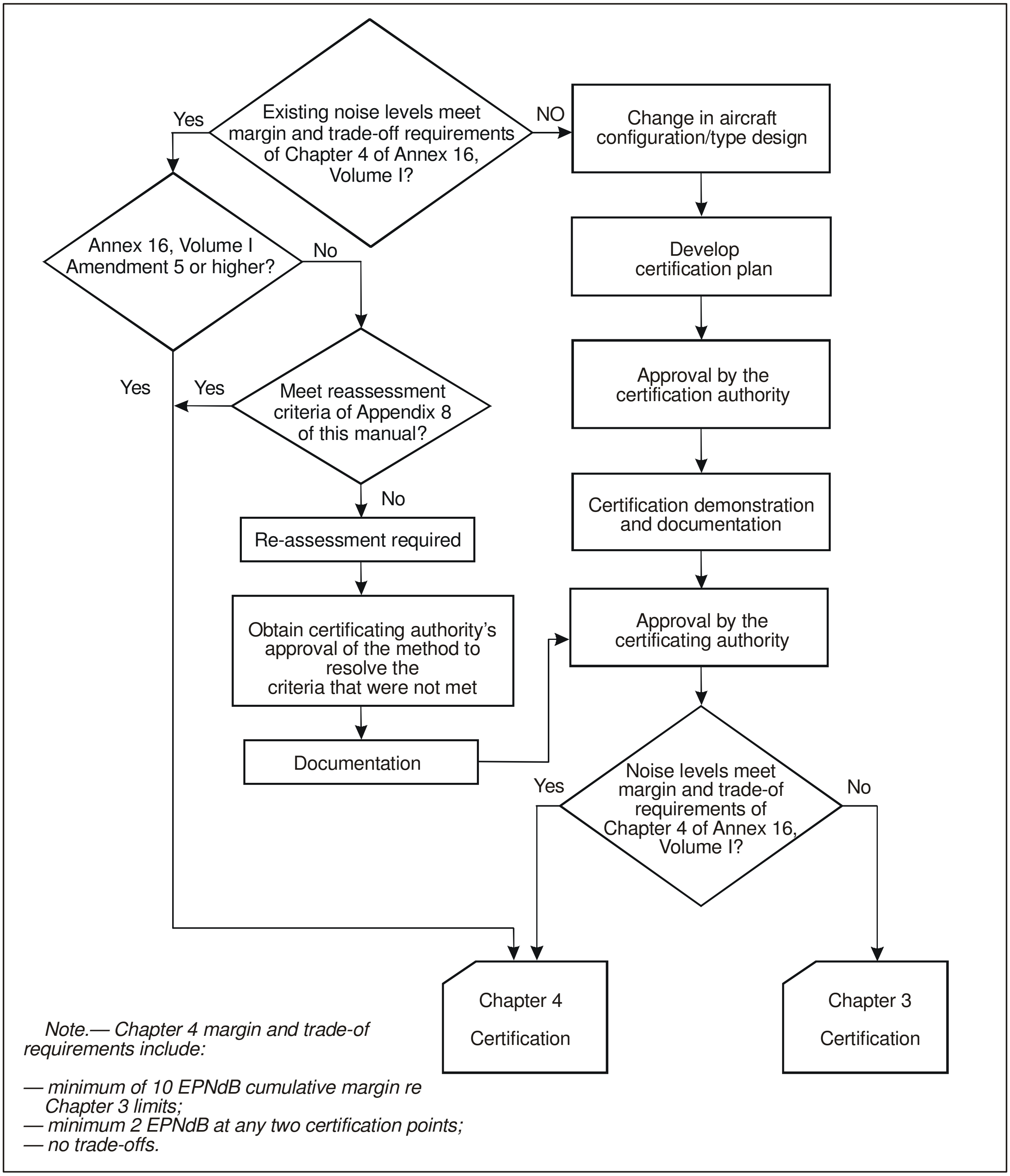
2.1.1 Section 2.2 is concerned with the assessment of existing approved noise levels associated with applications for the re-certification of an aeroplane from Chapters 3 or 5 to Chapter 4 of Annex 16, Volume I. Section 2.3 is concerned with the re-certification of an aeroplane from Chapter 2 to Chapter 4. Section 2.4 is concerned with the re-certification of an aeroplane from the United States Federal Aviation Administration (FAA) Part 36, Stage 3 to Chapter 4.

2.1.2 In applying the assessment criteria of each section, if the applicant is able to answer in the affirmative, to the satisfaction of the certificating authority, all the questions that may be relevant, then reassessment is not required. The existing approved Chapter 3, Chapter 5 or Stage 3 noise levels of the aeroplane should be used to determine compliance with the new Standard. Otherwise, in order to satisfy the requirements of the certificating authority, the applicant may propose additional analysis or data. Such analysis may lead to an adjustment being applied to the existing approved Chapter 3, Chapter 5 or Stage 3 noise levels. The applicant, at its discretion, may elect to provide new test data in place of, or in addition to, the analysis.

*Note.— The certificating authority's assessment of the suitability of the existing approved noise levels for compliance with the requirements of Chapter 4 will include a review of any equivalencies proposed by the applicant to meet the assessment criteria.*

### 2.2 Re-certification from Chapters 3 or 5 to Chapter 4

Noise levels already approved to Chapters 3 or 5 and submitted in support of applications for re-certification of



*Note.— Chapter 4 margin and trade-of requirements include:*

*— minimum of 10 EPNdB cumulative margin re Chapter 3 limits;*
*— minimum 2 EPNdB at any two certification points;*
*— no trade-offs.*

**Figure A8-1. "Road map" for re-certification of subsonic jet aeroplanes**

existing aircraft should be assessed against the criteria presented in this section. These criteria have been developed to ensure satisfactory compliance with the new Standard. The criteria consist of a list of simple questions concerning the manner in which the original Chapter 3 or Chapter 5 data was obtained and subsequently processed. The questions are the result of a comparison of the various amendments and revisions to Annex 16 and to this manual to which an aircraft's existing Chapter 3 and Chapter 5 noise levels may have been approved.

2.2.1 For aeroplanes which were approved in accordance with Amendment 5 or higher of Annex 16, Volume I, a reassessment is not required. The aeroplane's existing approved Chapter 3 or Chapter 5 noise levels should be used to determine compliance with the new Standard.

2.2.2 For aeroplanes which were approved in accordance with Amendment 4 or lower of Annex 16, Volume I, the applicant should be required to show that the existing approved Chapter 3 or Chapter 5 noise levels are equivalent to those approved to Amendment 5 by answering the following questions: (Note that section references refer to either Amendment 5 of Annex 16, Volume I or WGAR/6 of this manual. WGAR stands for Working Group Approved Revision.)

For all aeroplanes

a) Was full take-off power used throughout the reference flight path in the determination of the lateral noise level? (See 3.6.2.1 c) of Chapter 3 of Annex 16, Volume I, Amendment 5.)

b) Was the "average engine" rather than the "minimum engine" thrust or power used in the calculation of the take-off reference flight path? (See 3.6.2.1 a) and 3.6.2.1 g) of Chapter 3 of Annex 16, Volume I, Amendment 5.)

*Note.— The applicant may demonstrate compliance with Chapter 4 requirements by determining the lateral and flyover noise levels by adding a delta dB corresponding to the difference between the average and the minimum engine, as derived from approved noise-power-distance (NPD) data based on the aeroplane performance changes due to this difference.*

c) Was the "simplified" method of adjustment defined in Appendix 2 of Annex 16, Volume I used and, if so, was –7.5 used as the factor in the calculation of the noise propagation path duration correction term? (See 9.3.3.2 in Appendix 2 of Annex 16, Volume I, Amendment 5.)

d) Was the take-off reference speed between *V2+10 kt* and *V2+20 kt*? (See 3.6.2.1 d) of Chapter 3 of Annex 16, Volume I, Amendment 5.)

*Note.— The take-off reference speed used to demonstrate compliance with Chapter 4 requirements shall meet the requirements of 3.6.2.1 d) of Chapter 3 of Annex 16, Volume I, Amendment 5.*

e) Was the four half-second linear average approximation to exponential averaging used and, if so, were the 100 per cent weighting factors used? (See 3.4.5 and 3.4.6 of Appendix 2 in Annex 16, Volume I, Amendment 5.)

*Note.— The applicant is required to demonstrate compliance with the requirements of 3.4.5 of Appendix 2 in Annex 16, Volume I, Amendment 5, which equate to an exponential averaging process for the determination of SLOW weighted sound pressure levels. Simulated SLOW weighted sound pressure levels may be obtained by using one of the two equations described in 3.4.5 and 3.4.6 in Appendix 2 of Annex 16, Volume I, Amendment 5, as appropriate, or by other methods as approved by the certificating authority.*

For jet aeroplanes only

f) Were the noise measurements conducted at a test site below 366 m (1 200 ft) and, if not, was a jet source noise correction applied? (See Appendix 6 of WGAR/6 of this manual.)

g) Do the engines have bypass ratios of more than 2 and, if not, was the peak lateral noise established by undertaking a number of flights over a range of heights? (See 2.1.3.2 b) in Chapter 2 of WGAR/6 of this manual.)

h) In the event that "family" certification methods were used, were the 90 per cent confidence intervals for the pooling together of flight and static engine test data established according to the Technical Manual guidance? (See Appendix 1 of WGAR/6 of this manual.)

i) Do the engines have bypass ratios of 2 or less and, if not, in the event that "family" certification methods were used, did all associated static engine tests involve the use of a turbulence control screen (TCS) or inflow control device (ICD)? (See 2.3.3.4.1 in Chapter 2 of WGAR/6 of this manual.)

For propeller-driven aeroplanes only

j) Were symmetrical microphones used at every position along the lateral array for the determination of the peak lateral noise level? (See 3.3.2.2 in Chapter 3 of Annex 16, Volume I, Amendment 5.)

k) Was the approach noise level demonstrated at the noisiest configuration? (See 3.6.3.1 e) in Chapter 3 of Annex 16, Volume I, Amendment 5.)

l) Was the target airspeed flown during the flight tests appropriate to the actual test mass of the aeroplane? (See 3.1.2 a) in Chapter 3 of WGAR/6 of this manual.)

### 2.3 Re-certification from Chapter 2 to Chapter 4

2.3.1 Many aircraft originally certificated to the Standards of Chapter 2 of Annex 16, Volume I may have already been re-certificated to the Standards of Chapter 3. In such a case the approved Chapter 3 noise levels may be assessed for compliance with Chapter 4 according to the criteria of 2.2 of this appendix. For a Chapter 2-aircraft not already re-certificated to Chapter 3, noise data originally developed to demonstrate compliance with the requirements of Chapter 2 should first be corrected in an approved manner to the requirements of Chapter 3 of Annex 16, Volume I before the data are assessed against the requirements of Chapter 4.

2.3.2 In the assessment of data submitted in support of an application for the re-certification of an aeroplane from Chapter 2 to Chapter 3, the recommendations of 3.2.1 of this appendix should be followed.

### 2.4 Re-certification from United States FAR Part 36 Stage 3 to Chapter 4

Noise levels already approved to United States FAR Part 36, Stage 3 and submitted in support of applications for re-certification of existing aircraft to Chapter 4 should be assessed against the criteria presented as follows.

2.4.1 For Stage 3 aeroplanes which were approved in accordance with United States FAR Part 36, Amendment 24 (effective date 7 August 2002) or higher, the only assessment criterion of 2.2 of this appendix that may not have been satisfied is criterion g). Aside from consideration of criterion g), the existing approved United States FAR Part 36, Stage 3 noise levels of the aeroplane should be used to determine compliance with Chapter 4.

2.4.2 For Stage 3 aeroplanes which were approved in accordance with Amendments 7 through 23 of United States FAR Part 36, in addition to the re-assessment criteria of 2.2 of this appendix, the following criteria should also be considered.

a) Was the speed component of the Effective Perceived Noise Level (EPNL) duration adjustment determined by using $10 \log V/V_r$? (See 9.3.3.2 of Appendix 2 of Annex 16, Volume I, Amendment 5.)

b) For derivative engine certifications using static engine test procedures, is the summation of the magnitudes, neglecting signs, of the noise changes for the three reference certification conditions between the “flight datum” aeroplane and derived version not greater than 5 EPNdB with a maximum 3 EPNdB, at any one of the reference conditions? (See 2.3.2.4 in Chapter 2 of this manual.)

*Note.— These limitations may be exceeded under the circumstances described in 2.3.2.5 in Chapter 2 of this manual.*

## 3. RE-CERTIFICATION GUIDELINES FOR “MODIFIED” AEROPLANES

An existing aeroplane may have been approved with Chapter 3 or Chapter 5 noise certification levels that are higher than the maximum levels required by Chapter 4. For such an aeroplane to be considered for re-certification to Chapter 4, it will be necessary to “modify” the aeroplane in order to lower its noise levels below the limits required by Chapter 4. In order that certificating authorities evaluate applications for re-certification of “modified” aeroplanes in a consistent manner, the guidelines described in this section should be followed. These guidelines will be developed to cover other “modification” possibilities.

### 3.1 Operational Limitations

Operational limitations may be imposed on a re-certificated aircraft as a condition of compliance with the new noise certification requirements. In this context, an “operational limitation” is defined as a restriction on either the configuration or manner in which an aircraft may be flown which is applied in such a way that it is dependent on the will of the pilot and may otherwise be breached.

#### 3.1.1 *Flap deflection*

For the noise certification demonstration on approach:

- Only the most critical flap deflection (i.e. that which gives the highest noise level) shall be certificated. Noise levels for other flap deflections may be approved only as supplementary information, and should be determined in conformity with 3.6.1, 3.6.3 and 3.7 of Chapter 3 of Annex 16, Volume I and 2.1 and 2.2 of this manual by using the same demonstrations as for the most critical flap deflection.
- Typically for a jet aeroplane, the most critical flap configuration is associated with the maximum flap deflection. If the aircraft in its original state cannot comply with the requirements at the maximum flap deflection or, if an applicant wishes to have an aircraft certificated at less than maximum deflection, the flap deflection must be limited by means of a physical limit which, for the sake of prudence, may be frangible. A simple flight manual limitation is not acceptable. It is only permitted to exceed the frangible limit in case of an emergency situation, defined here as an unforeseen situation which endangers the safety of the aeroplane or persons necessitating the violation of the operational limitation. In such cases the frangible device must be replaced according to established maintenance practices and recorded in the aircraft log, before the next flight. Reference to emergency exceedance of the frangible limit must be incorporated into only the emergency procedures section of the aircraft flight manual.
- It is necessary to either actually fly the approach profile defined in 4.5 in Chapter 4 of Annex 16, Volume I, or, if the reference profile is not flown, the effect of all parameters (e.g. aircraft incidence angle) that may influence the noise levels must be shown and suitable corrections to the test results applied.
- It should be noted that in the case of a re-certificated propeller-driven aeroplane, the most critical flap configuration may not be associated with the maximum flap deflection and all normally permitted flap deflections must be flown in order to determine the noisiest configuration.

#### 3.1.2 *Propeller speed*

The demonstration of the noise certification level on approach must be made with the aircraft in its most critical (i.e. that which produces the highest noise level) configuration. For propeller-driven aeroplanes, the configuration includes the propeller rotational speed. For a re-certificated propeller-driven aeroplane, only the noisiest propeller speed defined for normal operation on approach may be approved. It should not be acceptable to define an alternative normal procedure using a different “quieter” (typically slower) propeller speed. A noise level for such a procedure may be approved as supplementary information only.

#### 3.1.3 *Maximum authorized take-off and landing mass*

It may be possible to lower the noise certification levels of an aeroplane by lowering its maximum authorized take-off and/or landing masses. An individual aircraft shall be certificated at only one pair of maximum take-off and landing masses at any one time. Noise levels for other masses may be approved only as supplementary information.

#### 3.1.4 *Take-off thrust de-rate*

If a de-rating of take-off thrust is used, a method for control of this thrust is required. The methods that may be available, at the discretion of the certification authority, could include a physical or electronic control, engine re-designation, and flight manual limitation. De-rated take-off thrust defined for noise purposes must be equal to the take-off operating thrust limit for normal operation and may be exceeded in an emergency situation. In all cases the flight manual limitations and performance sections must be consistent.

### 3.2 Demonstration Methods

#### 3.2.1 *Demonstration of lateral noise measured at 650 m*

The location of the noise measurement points for measuring lateral noise is defined in Chapter 2 of Annex 16, Volume I as being along a line parallel to, and 650 m from, the extended runway centreline. In the case of an aeroplane re-certificated to Chapter 4 but initially certificated as Chapter 2, lateral noise data taken at a lateral offset of 650 m shall only be acceptable if it is corrected to an offset of 450 m by means of the “integrated” method of adjustment. In such cases, at any particular time, the "measured" and "reference" emission angles must be the same.

### 3.2.2 *Centre of gravity position during take-off*

The demonstration of approach noise level must be made with the aircraft in its most critical (i.e. noisiest) configuration. Configuration includes the location of the centre of gravity position which, for approach, is most critically fully forward. No such restriction exists for the demonstration of take-off noise levels and the applicant is therefore free to select any configuration provided it is within the normal limits defined in the flight manual. In the case of a re-certificated aeroplane, the centre of gravity position used in the definition of the reference take-off profile must be within the normal certified range.

**— END —**

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