ICAO COMMITTEE ON AVIATION ENVIRONMENTAL PROTECTION

ENVIRONMENTAL TECHNICAL MANUAL ON THE USE OF PROCEDURES IN THE NOISE CERTIFICATION OF AIRCRAFT

STEERING GROUP APPROVED REVISION

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ICAO ENVIRONMENTAL TECHNICAL MANUAL ON THE USE OF PROCEDURES IN THE NOISE CERTIFICATION OF AIRCRAFT

This Steering Group approved revision includes material which has been approved by the relevant Working Groups of the ICAO Committee on Aviation Environmental Protection (CAEP). Its purpose is to make available new information to certificating authorities, noise certification applicants and other interested parties as soon as it has been agreed by the working groups, therefore eliminating the delay which would otherwise occur should its publication be limited only to post CAEP meetings. Prior to these meetings the then current approved revision will be reviewed for submission to CAEP for formal endorsement and subsequent publication by ICAO.

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NOMENCLATURE

Symbols and abbreviations employed in this manual are consistent with those contained in ICAO Annex 16, Volume 1, 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.
EPNL	EPNdB	Effective Perceived Noise Level
F	N	Engine net thrust
f	Hz	1/3-octave band centre frequency
ICD	-	Inflow control device
K	-	Constant
L	dBA	'A' - weighted sound pressure level
M	-	Mach number
M_H	-	Propeller helical tip Mach number
MAP	in. Hg	Manifold air pressure
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
PNLTM	TPNdB	Maximum Tone Corrected Perceived Noise Level
S	-	Strouhal number (fD/V_j)
SHP	kW	Shaft horse power
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 ground plane microphone height
V_j	m/sec	Jet velocity for complete isentropic expansion to ambient pressure
V	m/sec	Aircraft airspeed
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
δ_{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)
θ_{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)
μ	-	Engine power related parameter, or mean value see Appendix 1
λ	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
σ	-	Ratio of atmospheric air density at altitude to that at sea level for ISA conditions

Suffices

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

ESDU	Engineering Sciences Data Unit
ISA	International Standard Atmosphere
NPD	Noise-power-distance
SAE AIR	Society of Automotive Engineers - Aerospace Information Report
SAE ARP	Society of Automotive Engineers - Aerospace Recommended Practice

Notes: Where log is used in this document it denotes logarithm to the base of 10.

SECTION 1 - GENERAL

1.1 PURPOSE

1.1.1 The aim of this manual is to promote uniformity of implementation of the technical procedures of Annex 16, Volume 1, and to provide guidance such that all certificating authorities can apply the same degree of stringency and the same criteria for acceptance in 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 1. Such procedures are referred to in Annex 16, Volume 1, but are not dealt with in the same detail as in the Appendices to the Annex which describe the noise evaluation methods for compliance with the relevant Chapters.

1.1.3 Annex 16, Volume 1, 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 1, 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 1, relate to the Amendment 6 thereof.

1.2 FRAMEWORK

Equivalent procedures fall into two broad categories; those which are generally applicable and 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 turbojet powered aeroplanes, and not to turboprop powered aeroplanes. Consequently this manual is framed to provide information on equivalent procedures applicable to the types of aircraft covered by Annex 16, Volume 1, i.e. jet powered, propeller driven heavy and light aeroplanes and helicopters. Equivalent procedures applicable to each aircraft type are identified in separate sections. Each section 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. Approval of this plan and the proposed use of any equivalent procedure remains with the certificating authority. The procedures in this manual are grouped for 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 for a certificate.

1.3.2 Use of equivalent procedures may be requested by certificate 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 minimise the costs of demonstrating compliance with the requirements of Annex 16, Volume 1, 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 adjustment of 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 1, flight test demonstration).

1.4.2 The physical differences between the "flight datum" aircraft and the derived version can take many forms, for example, an increased take-off weight, an increased engine thrust, changes to the powerplant or propeller or rotor types, etc. Some of these 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, for example, 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 levels that are not acoustically significant. These are referred to as no-acoustical changes. For this manual, no-acoustical changes, which do not result in modification of an aircraft's certificated noise levels, are defined as:

a) Changes in aircraft noise levels approved by certificating authorities as not exceeding 0.1 dB at any noise measurement point and which an applicant does not track;

b) Cumulative changes in aircraft noise levels approved by certificating authorities 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.

1.4.4 Noise certification approval has been given for a tracking procedure of the type identified in 1.4.3b, based upon the following criteria:

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

b) When 0.3 dB cumulative is exceeded, compliance with Annex 16 Volume 1 requirements is required. The aircraft certification noise levels may not be based upon summation of no-acoustical change noise increments;

c) Noise level decreases 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. 0.01dB). Round-off shall not be considered in judging a no-acoustical change (e.g. 0.29dB = no-acoustical change ; 0.30dB = no-acoustical change ; 0.31dB = acoustical change);

i) An applicant should maintain formal documentation of all no-acoustical changes 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 applicable dates for Chapters 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 which case the no-acoustical criterion application will be treated with a procedure approved by the certificating authority.

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 ICAO Annex 16, Volume 1, Chapter 3 to a more stringent standard that may be directly applicable to new types only, 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 described in paragraph 1.5.2 should be assessed is presented in Appendix 8.

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SECTION 2 - EQUIVALENT PROCEDURES FOR SUBSONIC JET POWERED 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 Section 2.6 of Annex 16, Volume 1, for Chapter 2 aeroplanes and Section 3.6 for Chapter 3 aeroplanes). In addition, the Annex 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 Annex 16, Volume 1, Chapters 2 and 3 procedures for turbo-jet and turbo-fan powered 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 paragraphs 9.2 and 9.3 of Appendix 1 or paragraphs 9.2 of Appendix 2 of Annex 16, Volume 1, have been used to meet the demonstration requirements of noise certification. The intercept procedures have also been used in the implementation of the generalised flight test procedures described in Section 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 and increased consistency and quality in noise data are obtained.

2.1.1.2 Figure l(a) illustrates a typical take-off profile. The aeroplane is initially stabilised 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 cutback power is employed, point E is the point of application of power cutback and 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 synchronised with the noise measurement at K.

2.1.1.3 For approach, the aeroplane usually follows the planned flight trajectory while maintaining a constant configuration and power until no influence on the noise levels within ten decibels of PNLTM. The aeroplane then carries out a go-around rather than continuing the landing (See Fig. 1(b)).

2.1.1.4 For the development of the noise-power-distance data for the approach case (see 2.1.2.1) the speed, and approach angle constraints imposed by Annex 16, Volume 1 in 2.6.2 and 3.6.3 and 3.7.5 cannot be satisfied over the typical ranges of thrust needed. For the approach case speed shall be maintained at 1.3 V_S + 19 km/h (1.3 V_S + 10 kt) to within ±9 km/h or ±5 kt and flyover height over the microphone maintained at 400 ft ±100 ft. However the approach angle at the test thrust shall be that which results from the aircraft conditions, ie. mass, configuration, speed and thrust.

2.1.1.5 The flight profiles should be consistent with the test requirements of the Annex over a distance that corresponds at least to noise levels 10 dB below the maximum tone corrected Perceived Noise Level (PNLTM) obtained at the measurement points during the demonstration.

2.1.2 Generalised flight test procedures

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

2.1.2.1 *Derivation of noise, power, distance data*

2.1.2.1.1 For a range of powers covering full take-off and cut-back powers, the aeroplane is flown past lateral and under-flight-path microphones according to either the take-off procedures defined in paragraph 3.6.2 of Volume 1 of Annex 16 or, more typically, flight path intercept procedures described in Section 2.1.1 of this manual. Target test conditions are established for each sound measurement. These target 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. (As an example if the appropriate take-off reference airspeed for the aeroplane is V_2+15 kt 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. (As an example if the approximate take-off reference airspeed for the aeroplane is V_2+15 kt 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 to enable noise-power curves at a given distance for both lateral and flyover cases to be established. 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 generalised noise data base for use in the noise certification of the "flight datum" and derived versions of the type and are often referred to as Noise-Power-Distance (NPD) plots(see Fig. 2). If over any portion of the range for the NPD plot the criteria for calculating the EPNdB given in paragraphs 9.1.2 and 9.1.3 of Appendix 2 of Annex 16, Volume 1, requires the use of the integrated procedure, this procedure shall be used for the whole NPD. The 90 per cent confidence intervals about the mean lines are constructed through the data (see paragraph 2.2 of Appendix 1).

Note: The same techniques can be used to develop NPD’s appropriate for the derivation of 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 paragraph 3.6.3 of Annex 16, Volume 1, or more typically, flight test procedures described in 2.1.1 of this manual.

2.1.2.1.3 Availability of flight test data for use in data adjustment, e.g. speed and altitude, should be considered in test planning and may limit the extent to which a derived version may be developed 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 provided that jet noise source corrections are applied to the noise data. The correction method of Appendix 6 has been approved for this purpose.

2.1.2.1.4 The take-off, 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 (Chapter 2 aeroplanes) or Appendix 2 (Chapter 3 aeroplanes) of Annex 16, Volume 1. The NPD plots can then be constructed from the corrected Effective Perceived Noise Level (EPNL), power and distance information. The curves present the EPNL value for a range of distance and engine noise performance parameters, (see Annex 16, Volume 1, paragraph 9.3.4.1 of Appendix 2). The parameters are usually the corrected low pressure rotor speed $N_1 \big/ \sqrt{\theta_{t_2}}$ or the corrected net thrust $F_N / \delta_{\text{amb}}$ (see Fig. 2), where:

N_1 is the actual low pressure rotor speed;

θ_{t_2} 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 (ie. 288.15 °K);

F_N is the actual engine net thrust per engine; and

δ_{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 (ie. 101.325 kPa).

2.1.2.1.5 Generalised 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 *Procedures for the determination of changes in noise levels*

Noise level changes determined by comparison of flight test data for different developments 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 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).

2.1.3 **The 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 has proved to be effective in terms of time and costs savings. Such an arrangement avoids many of the difficulties encountered in using the more conventional multi-microphone arrays. The procedures consist of flying the test aeroplane at full take-off power at one (or more) specified heights above a track at right angles to and midway along the line joining the two microphone stations. However, when this procedure is used matching data from <u>both</u> 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 turbo-jet or turbo-fan 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* (1,427 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 Chapter 3 or Chapter 2 of Annex 16, Volume 1, two microphone locations are used, symmetrically placed on either side of the aeroplane reference flight track and 450 m or 650 m* from it;

b) for aeroplanes with engines having bypass ratios of more than 2, the height of the aeroplane as it passes the microphone stations should be 300 m (985 ft) or 435 m* (1,427 ft) and be no more than +100 m, -50 m (+328 ft, -164 ft) relative to this target height. For aeroplanes with bypass ratios 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 (2000 ft) above the inter-section 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 paragraphs 3.6.2.1 a), 3.6.2.1 d), 2.6.1.2 and 2.6.1.3 of Annex 16, Volume 1, 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 Appendix 1 and 2 of Annex 16, Volume 1; and

e) to account for any possible asymmetry effects in measured noise levels, the reported lateral noise level for purposes of demonstrating compliance with the applicable noise limit of Chapter 3 or Chapter 2 of Annex 16, Volume 1, as applicable, should be the arithmetic average of the corrected maximum noise levels from each of the two lateral measurement points and compliance should be determined within the ±1.5 dB 90 per cent confidence interval required by the Annex (see paragraph 2 of Appendix 1 of this manual).

2.1.3.3 Lateral noise certification level determination has also been accomplished 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 to adequately define the maximum lateral noise certification level and provide an acceptable 90 per cent confidence interval.

2.1.4 Take-off flyover noise levels with power cut-back

Flyover noise levels with power cut-back may also be established without making measurements during take-off with full power followed by power reduction in accordance with paragraph 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 Annex 16, Volume 1, Chapters 2 and 3, paragraphs 2.3.1 and 3.3.1. Under these circumstances an applicant may request approval of data that have been adjusted from the actual measurements to represent data that would have been measured at the reference points in reference conditions.

2.1.5.2 Reasons for such a request 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

* For Chapter 2 procedures.

a greater ratio of signal to background noise. Whereas Appendix 3 describes a procedure for removing the effects of ambient 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 certification data base 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 station(s) which could influence sound measurements. When a flight path intercept technique is being used, take-off and approach noise measurement stations may be relocated as necessary to avoid undesirable obstructions. Sideline measurement stations 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 1, and the magnitudes of the adjustments do not exceed the limitations in section 5.4 of Appendix 1 and paragraph 3.7.6 of Chapter 3 of the Annex.

2.1.6 **Atmospheric test conditions**

It has been found acceptable by certificating authorities to exceed the sound attenuation limits of Annex 16, Volume 1, Appendix 2, Section 2.2.2(c) when:

a) 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 PNLT, after adjustment to reference conditions, occur at frequencies of less than or equal to 400 Hz.

2.1.7 **Reference approach speed**

The reference approach speed is currently contained in 3.6.3.1(b) of Chapter 3 of Annex 16, Volume 1 as 1.3 V_S + 19 km/h (1.3 V_S + 10 kt). There is a change being made to the definition of stall speed, for airworthiness reasons, to alter the current minimum speed V_S definition to a stall speed during a 1-g manoeuvre (ie. a flight load factor of unity) V_{S1g}. In terms of the new definition the approach reference speed becomes 1.23 V_{S1g} + 19 km/h, (1.23 V_{S1g} + 10 kt) which can be taken as equivalent to the reference speed contained in Chapter 3.

2.2 ANALYTICAL PROCEDURES

Analytical equivalent procedures rely upon available noise and performance data obtained from flight test for the aeroplane type. Generalised relationships between noise, power and distance (NPD plots see 2.1.2.1) and adjustment procedures for speed changes in accordance with the methods of Appendix 1 or 2 of Annex 16, Volume 1, 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 paragraph 2.1.2.2 of this manual.

2.2.1 **Flyover noise levels with power cut-back**

Note: The "average engine" spool-down time should reflect a 1.0 second minimum altitude recognition lag time to account for pilot response.

2.2.1.1 Flyover noise levels with power cut-back may be established from the merging of PNLT versus time measurements obtained during constant power operations. As seen in Fig. 4(a) the 10 dB-down PNLT noise time history recorded at the flyover point may contain portions of both full power and cut-back power noise time histories. Provided these noise time histories, the average engine spool-down thrust characteristics and the aeroplane flight path during this period (See Fig. 4(b)), which includes the transition from full to cut-back power, are known, the flyover noise level may be computed.

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

Note: To ensure that the full power portion of the noise time history does not intrude upon the 10 dB-down noise levels, $PNLTM_{after\,cutback} - PNLT_{before\,cutback} \geq 10.5\ dB$

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 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;

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 Effective Perceived Noise Level 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 extension of the NPD are:

- the 90% confidence interval at the extended 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 EPNL of less than one decibel. However, it should 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 these to flight conditions in a manner similar to the static test procedure described in paragraph 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 paragraph 2.3 an EPNL representative of flight conditions should be computed by adjusting aeroplane component noise sources for forward speed effects, 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 certification levels should be made using the procedures in paragraphs 2.3.4.12 and 2.3.4.13. Guidance material on confidence interval computations is provided in Appendix 1.

d) airframe design changes such as changes in fuselage length, flap configuration and engine installation, that could indirectly affect noise levels because of an effect on aeroplane performance (increased drag for example). 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 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 need to be established by test.

2.3 STATIC TESTS AND PROJECTIONS TO FLIGHT NOISE LEVELS

2.3.1 General

2.3.1.1 Static test evidence provides valuable definitive information for deriving the noise levels resulting from changes to an aeroplane powerplant or 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 whereby 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 test information depends critically upon the availability of an adequate approved data base (NPD plot) acquired from the flight testing of the flight datum aeroplane.

2.3.1.3 Static tests can provide sufficient additional data or noise source characteristics to allow a prediction to be made of 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 testing is dealt with in detail in subsequent sections. The criteria for acceptance of component tests are less definable. There are many instances, particularly when only small EPNL changes are expected, that component testing provides an adequate demonstration of noise impact. These include, 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 the 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 EPNL of the aeroplane.

2.3.2 Limitation on the projection of static to flight data

Details of the acceptability, use and applicability of static test data are contained in subsequent sections.

2.3.2.1 The amount by which the measured noise levels of a derivative engine will differ from 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.

2.3.2.2 Additionally, day-to-day and test site-to-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) above, when extrapolated to flight conditions, are constrained to acceptable amounts before a new flight test is required, a limit is needed that can be used uniformly by certificating authorities.

2.3.2.3 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 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 5).

2.3.2.4 For differences greater than this additional flight testing at conditions where noise levels are expected to change is recommended to establish a new flight NPD data base.

2.3.2.5 Provided the detailed prediction procedures used are verified by flight test for all the types of noise sources, ie. tones, non-jet broadband and jet noise relevant to the aeroplane under consideration and 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 above.

2.3.2.6 In addition to the limitations described above a measure of acceptability regarding methodologies for static to flight projection is also needed that can be used uniformly by certificating authorities. This measure can be derived as 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 residuals to 3 EPNdB at any one of the reference conditions.

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

2.3.3 **Static engine tests**

2.3.3.1 *General*

2.3.3.1.1 Data acquired from static tests of engines of similar designs to those that were flight tested may be projected, when appropriate, to flight conditions and, after approval, used to supplement an approved NPD plot for the purpose of demonstrating compliance with the Annex 16, Volume 1, provisions in support of a change in type design. This section provides guidelines on static engine test data acquisition, analysis and normalisation 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) ARP 1846, "Measurement of Noise from Gas Turbine Engines During Static Operation". The engine designs and 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. Note that test restrictions defined for flight testing in conformity with Annex 16, Volume 1, are not necessarily appropriate for static testing. (SAE ARP 1846 provides guidance on this subject).

2.3.3.1.2 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 permitted for flight testing by Annex 16, Volume 1. 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 differing engine configurations provided the acoustic measurements from the different sites can be adjusted to a common reference condition.

2.3.3.3 *Engine inlet bell mouth*

The installation of a bell mouth forward of the engine inlet may be used with turbofan or turbojet engines during static 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*

2.3.3.4.1 The use of static engine test noise data for the noise certification of an aeroplane with a change of engine to one of a similar design requires the use of 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 paragraph 2.3.3.4.3) to determine its effect on sound transmission in each one-third octave band;

c) Data obtained during static testing must be corrected to account for sound transmission effects that are caused by the ICD. The corrections 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 corrections if the same ICD hardware (identical serial number) is used as was previously used in the static noise test of the flight engine configuration, and the fan tones for both engines remain in the same one-third octave bands.

2.3.3.4.3 <u>ICD calibration</u>

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 50 ft and 150 ft that provides a good signal-to-ambient noise ratio and 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 2 ft of the acoustic centre of the acoustic driver(s);

b) Energise the acoustic driver with pink noise without the ICD in place. Record the noise for a minimum of 60 s duration following system stabilisation. 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 corrected for sound pressure level variations as measured with the near-field microphone and for atmospheric absorption to 77 °F and 70 per cent RH conditions 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 corrected SPL's without the ICD in place and the average of the corrected SPL's 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 SPL data. Refer to Figure 6, Section 2.3.3.7.

In some cases large fluctuations in the value of the calibrations across adjacent 1/3 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 effective perceived noise levels 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

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. 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 normalisation. 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 near ground plane microphone height (TMIC).

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 6.

The line 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 s) 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.

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 stabilised engine power settings over the desired range should be included in the test to ensure that the 90 per cent confidence intervals in flight projected EPNL can be established (see paragraph 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 turbo-fan engines is an acceptable alternative to using actual engine noise measurements for analysis system compatibility determination. 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 normalisation*

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 normalised to consistent conditions and include 24 1/3-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).

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 normalised to account for the effects identified in 2.3.3.8. 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) effects of source motion including Doppler effects;

b) number of engines and shielding effects;

c) installation effects;

d) flight geometry;

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

f) flight propagation effects including ground reflection and lateral attenuation. (See paragraph 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 1/3 octave-band spectral data to flight conditions, Effective Perceived Noise Levels 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 Figs 7 and 8.

2.3.4.1.4 It is not intended that the procedure illustrated in Figs 7 and 8 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 Effective Perceived Noise Level 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 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 *Normalisation to reference conditions*

2.3.4.2.1 The analysed static test data should be normalised to freefield conditions in the Annex 16, Volume 1 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 paragraphs 2.3.4.3 to 2.3.4.5.

2.3.4.2.2 The required adjustments include:

a) A*tmospheric absorption*: adjustments to account for the acoustical reference day atmospheric absorption are defined in SAE ARP 866A (revised 15th 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 freefield sound pressure levels are described in SAE AIR 1672B-1983 or 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, 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 1/3 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 that used in Annex 16, Volume 1, Chapter 3 (Appendix 2) for tone correction purposes (that is, considering the slopes between adjacent 1/3 octave band levels). Care must be taken to avoid regarding tones as "non protrusive" when the surrounding broad band sound pressure level is likely to be lower when adjusted from static to flight conditions, or 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. 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, separation of sources of broadband noise into those due to external jet mixing and those generated internally can be carried out by estimating the jet noise by one or more of the methods identified below, and 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 means 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. However, the engine geometry may possess features which can render this method inapplicable. Example procedures for co-axial 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 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.

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.

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 paragraph 2.3.4.2 above.

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 generalised data base.

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 References 1 and 2):

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

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 1/3 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 and account should be taken of this. Noise source strengths may be changed accordingly. Therefore, values for key correlating parameters for component noise source generation should be based on the flight condition and the static data base should be entered at the appropriate correlating parameter value. Turbo-machinery noise levels should be based on the inflight corrected rotor speeds $N_1 / \sqrt{\theta_{t_2}}$ 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 data base 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 convective amplification effects. Broadly, 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 having circular exhaust geometries, SAE ARP 876C-1985 provides guidance. However, additional supporting evidence 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

λ = 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 1/3 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*: sound pressure level adjustments to airframe generated noise that result from speed changes between the datum and derivative version is provided for in paragraph 2.3.4.9, Airframe noise.

For noise generated internally within the engine, e.g. fan noise, there is no consensus of opinion on the mechanisms involved or 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 sound pressure level changes that result form the motion of the source (aeroplane) relative to the microphone may be accounted for using the 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 λ 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. However, it might be necessary 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 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 data base. The airframe-generated noise, which can be treated as a point source for adjustment purposes, is normalised to the same conditions as those of the other (engine) sources, with due account for the effects of spherical divergence, atmospheric absorption and airspeed as described in section 8 and 9 of Appendix 2 of Annex 16, Volume 1.

2.3.4.9.2 Airframe noise for a specific configuration varies with airspeed (see Reference 3) as follows:

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

where:

V_{REF} is 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, approval of the certification authority is required for values other than 50.

2.3.4.10 *Aeroplane flight path considerations*

When computing noise 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 1. Further, 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, as discussed earlier, together with the airframe noise and any installation effects, are summed 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 band-sharing of discrete frequency tones.

2.3.4.11.3 The effects of ground reflections must be included in the estimate of freefield sound pressure levels 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 Engineering Science Data Unit, ESDU data item 80038 Amendment A may be used to apply adjustments to the freefield spectra to allow for flight measurements being made at 1.2 m (4 ft). Alternatively, the ground reflection correction can be derived from other approved analytical or empirically derived models. Note that the Doppler correction 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 2.3.4.7.2(a).

2.3.4.11.4 This process is repeated for each measurement angle and for each engine power setting.

2.3.4.11.5 With regard to lateral attenuation, 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 flightpath. (*Note: 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 1, 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 versions of the engine or nacelle tested. Comparisons of the noise v's engine 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 Effective Perceived Noise Level.

2.3.4.13.2 The noise certification levels for the derived version may be obtained by entering the NPD plots at the relevant reference engine power and distance.

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SECTION 3 - EQUIVALENT PROCEDURES FOR PROPELLER DRIVEN AEROPLANES OVER 9000 kg

The following procedures have been used as equivalent in stringency to Chapter 3 and Chapter 5, Annex 16, Volume 1 for propeller driven aeroplanes with maximum certificated take-off mass exceeding 9000 kg.

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 Generalised flight test procedures

Generalised 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 generalised noise characteristics necessary for 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 NPD plots employ engine noise performance parameters (μ) of M_H (propeller helical tip Mach number) and SHP/δ_{amb} (shaft horse power) (see Fig 3), where δ_{amb} is defined in 2.1.2.1.3.

   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 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 by 5.6.3(b), 5.7.5, 3.6.3 and 3.7.5 of Chapters 5 and 3 of Annex 16, Volume 1, cannot be satisfied over the typical range of power needed. For the approach case the speed shall be maintained at 1.3 V_S + 19 km/h (1.3 V_S + 10 kt) to within ±6 km/h or ±3 kt and flyover height over the microphone maintained at 400 ft ±100 ft. However the approach angle at the test power shall be that which results from the aeroplane conditions, ie. mass, configuration, speed and power; and

b) *Noise level changes* determined by comparisons of fly-over noise test data for different developments of an aeroplane type, for example, a change in propeller type, have been 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

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 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.

3.1.3.1 The lateral Effective Perceived Noise Level 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.

3.1.3.2 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 inter-section of the track with this line is defined as the reference point.

3.1.3.3 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 stabilised to at least V_2 + 19 km/h (V_2 + 10 kt) over the 10 dB-down time period.

3.1.3.4 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 1.

3.1.3.5 The lateral certification noise level is obtained by finding the peak of the curve of noise level (EPNL) corrected to reference day atmospheric absorption values, plotted against aeroplane height above the reference point (see Fig. 9). 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).

3.1.3.6 To ensure that the requirements of 5.4.2 of Appendix 2 or 5.5.2 of Appendix 1 of Annex 16, Volume 1, are met the 90 per cent confidence limits should be determined in accordance with paragraph 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 specified in Chapters 3 and 5 of Annex 16, Volume 1. 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).

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 they are dominated by low frequency noise. The spectra rolls off rapidly at higher frequencies and is often lost in the background noise at frequencies above 5000 Hz. Appendix 3 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 Appendix 1 or 2 of Annex 16, Volume 1 and the magnitude of the adjustments does not exceed the limits in paragraphs 3.7.6 of Chapter 3 and 5.7.6 of Chapter 5 of the Annex.

3.1.5 **Reference approach speed**

The reference approach speed is currently contained in 3.6.3.1(b) of Chapter 3 of Annex 16, Volume 1 as 1.3 V_S + 19 km/h (1.3 V_S + 10 kt). There is a change being made to the definition of stall speed, for airworthiness reasons, to alter the current minimum speed V_S definition to a stall speed during a 1-g manoeuvre (i.e. a flight load factor of unity) V_{S1g}. In terms of the new definition the approach reference speed becomes 1.23 V_{S1g} + 19 km/h, (1.23 V_{S1g} + 10 kt) which can be taken as equivalent to the reference speed contained in Chapter 3.

3.2 Analytical Procedures

3.2.1 Analytical equivalent procedures rely upon available noise and performance data for the aeroplane type. Generalised relationships between noise levels, propeller helical tip Mach number, and shaft horsepower and correction procedures for speed and height changes in accordance with the methods of Appendix 2 of Annex 16, Volume 1, are combined with certificated aeroplane performance data 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 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 including 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. However, care is needed to ensure that 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 (increased drag for example). 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.

3.3 GROUND STATIC TESTING PROCEDURES

3.3.1 General

Unlike the case of a turbojet or turbo fan powerplant, static tests involving changes to the propeller are not applicable to determining noise level changes in the development of a propeller driven aeroplane/powerplant family. This is caused by 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 not normally important in flight. However, limited static tests on engines with propellers, which are used as engine loading devices can be utilised 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 power plants.

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 the internal structure of the engine in the frequency ranges where there is a contribution to the aeroplane EPNL, or where that part of the spectrum is clearly dominated by the gas generator or ancillary equipment under circumstances where the propeller and its aerodynamic performance remains unchanged.

3.3.3.2 Such circumstances 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 paragraph 2.3 for turbojet and turbofan engines. The noise 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.

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SECTION 4 - EQUIVALENT PROCEDURES FOR PROPELLER DRIVEN AEROPLANES NOT EXCEEDING 9000 kg

The following procedures have been used as equivalent in stringency to Chapter 6 and Chapter 10 of Annex 16, Volume 1 for propeller-driven aeroplanes with maximum certificated take-off mass not exceeding 9000 kg.

4.1 SOURCE NOISE ADJUSTMENTS

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

4.1.1 **Fixed pitch propellers**

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 paragraph 6.5.2 of Annex 16, Volume 1 at the propeller speed for maximum continuous power N_{MCP}. Aeroplanes demonstrating compliance with Annex 16, Chapter 10, should be flown according to paragraph 2.3 of Appendix 6 of Annex 16, Volume 1 such that the aircraft overflys the microphone at the reference height H_{REF} (defined in paragraph 5.1 of Appendix 6), the best rate of climb speed V_y and at the propeller speed, N_{MAX}, corresponding to that defined in paragraph d) of *Second Phase* of paragraph 10.5.2 of Annex 16. 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 (L_{Amax}) is plotted against propeller helical tip Mach number (M_H) to obtain the curve from which the source noise correction may be derived.

For fixed pitch propellers it is generally not possible via flight tests to separate out the two significant noise generating parameters, helical tip Mach number and power absorbed by the propeller. 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 it the effects not only of Mach number but also 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 data is 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 to establish a carpet plot of maximum A-weighted noise levels against propeller speed and torque, MAP or shaft horse power (SHP).

4.1.2.2 A plot of maximum A-weighted noise level (L_{Amax}), helical tip Mach number (M_H) and torque or MAP is developed which is used to derive the source noise adjustment (L_{Amax}) being 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 ISA and sea level conditions) to establish the engine power level under the test conditions of ambient temperature and air density, as follows:

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

for normally aspirated engines; and

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

for turbo-charged engines,

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 σ is the air density ratio. Note that in this context *reference* denotes the reference conditions for which the engine SHP is known.

4.2 TAKE-OFF TEST AND REFERENCE PROCEDURES

In planning a test programme for noise certification under Chapter 10 and Appendix 6, it is helpful to note the differences between test day flight procedures and the standardised 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 paragraph 10.5.2 of Chapter 10. They require that the first segment be computed, using airworthiness approved data, assuming take-off power is used from the brake release point to 15 m (50 feet) 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.

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 Annex 16, Chapter 10 is presented in Appendix (5) of this manual.

4.2.2 Requirements for aeroplane test procedures are contained in two places: Section 10.6 of Chapter 10 and Section 2.3 of Appendix 6. They basically only speak to test tolerances and approval of test plans by certificating authorities.

4.2.3 Figure 13 illustrates the difference between the two. 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.

SECTION 5 - EQUIVALENT PROCEDURES FOR HELICOPTERS

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 section 8.7 of Annex 16, Volume 1). In addition, the Annex 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

Noise certification of helicopters has been required fairly recently and many applicants may find that the current standards and procedures differ from those that they have used hitherto. The following paragraphs are designed to provide clarification of the requirements as set out in Chapter 8 and Appendix 2 of Annex 16, Volume 1.

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 1 (paragraph 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” (Figure 16) 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. That is the terms $0.01\left[\alpha(i)-\alpha(i)_0\right]QK$ and $0.01\alpha(i)_0\left(QK-Q_rK_r\right)$ from the equation for $SPL(i)_r$ in paragraph 8.3.1 of Appendix 2 of Annex 16, Volume 1, become zero and the adjustment becomes:

$$SPL(i)_r = SPL(i) + 20\log\left(QK/Q_rK_r\right)$$

In addition, provided that <u>all</u> the measured points for a particular flight condition are within the “zero attenuation adjustment window” defined in Figure 16 and are within the appropriate height tolerances for flyover of ±9 m (±29.5 ft), for approach ±10 m (±32.8 ft) and the 2 EPNdB limit on the take-off adjustment for height given in paragraph 8.7.4a of Chapter 8 of Annex 16, Volume 1, 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 it is over the centre noise measuring point.

The total effect of both simplifications is that the equation of paragraph 8.3.1 of Appendix 2 of Annex 16, Volume 1 becomes:

$$SPL(i)_r = SPL(i) + 20\log\left(HK/H_rK_r\right)$$

and the duration adjustment specified in paragraph 8.4.2 of Appendix 2 of Annex 16, Volume 1, becomes:

$$\Delta_2 = -7.5\log\left(HK/H_rK_r\right) + 10\log\left(V/V_r\right)$$

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, ie. within 9 km/h (5 kt), of the reference speed (see 8.7.6 of Volume 1 of Annex 16) to minimise 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 Volume 1 of Annex 16). When the absolute wind speed component in the direction of flight exceeds 9 km/h (5 kt) the level overflights shall be made in equal numbers with a head wind component and tail wind component. The objective is to counter the effect of the short duration correction obtained in the downwind direction with the larger one into wind. In steady wind conditions the net effect of flying into and with the wind would be zero.

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

5.1.1.3 *Test speed for light helicopters*

For the purposes of compliance with Chapter 11 of Annex 16, Volume 1, the helicopter should be flown at test speed V_{ar} which will produce the same advancing blade Mach number as the reference speed in reference conditions given in paragraphs 11.5.1.4 and 11.5.2 b) of Chapter 11 of Annex 16.

The reference advancing blade Mach number M_R is defined as the ratio of the arithmetic sum of the 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/sec) such that:

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

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 onboard measurements of outside air temperature.

Since the ground speed obtained from the overflight tests will differ from that for reference conditions an adjustment Δ_2 of the form:

$$\Delta_2 = 10\log\left(V_{ar}/V_{ref}\right)$$

will need to be applied. Δ_2 is the increment in decibels that must be added to the measured sound exposure level (SEL).

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 of Volume 1 of Annex 16) must lie within the range 90 per cent - 105 per cent of the maximum take-off mass for the take-off and flyover and between 90 per cent - 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 9 of Appendix 2, Annex 16, Volume 1.

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*

Section 8.7.10 of Chapter 8 in Annex 16 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 9 of Appendix 2, Annex 16, Volume 1.

5.1.1.6 *Helicopter flight path tracking*

Annex 16, Volume 1, Appendix 2, Section 2.3 requires that the helicopter position relative to the flight path reference point be determined and synchronised adequately with the noise data between the 10 dB-down points.

Methods which have been 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 below. 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 <u>Radar or microwave tracking system</u>

One example of a radar position tracking system is shown in Figure 14. 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 minimise 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 this data to a PCM recorder;

c) converts the aircraft range and height information into X, Y and Z position co-ordinates in real time; and

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

The accuracy of the co-ordinate calculation depends on the flight path and transponder geometry. Errors are minimised when ranges intersect and the recommended practice is to keep the intersection angle near to 90°. The four transponder arrangements shown in Figure 14 produce position uncertainties from ±1.0 to ±2.0 m.

Some inaccuracies at low aircraft heights can be introduced with the use of microwave systems and the use of a radio-altimeter can reduce the errors. The height data is recorded and synchronised with the microwave.

<u>Helicopter equipment</u>: 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.

<u>Ground equipment</u>: The four beacons are located on either side of the aircraft track to permit the optimum layout, ie. 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 central microphone, another two beacons can be located under track at ±600 m from the central microphone.

5.1.1.6.2 Kine-theodolite system

It is possible to obtain helicopter position data with classical kine-theodolites, but it is also possible to make use of a system composed of two simplified theodolites including a motorised photocamera on a moving platform reporting site and elevation. These parameters are synchronised with coded time and the identification number of every photograph recorded.

Each 0.1 s site and elevation data are sent by UHF to a central computer which calculates the helicopter position X, Y, Z, versus time for each trajectory.

Photography stations are located at sideline positions, about 300 m from the track, and at 200 m either side of the 3 noise measurement points.

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

5.1.1.6.3 Radar / theodolite triangulation

The opto-electronic system shown diagramatically in Figure 15 uses a single optical theodolite to provide azimuth and elevation while range data are obtained from a radar tracking system using a single transponder. Data from these two sources are transferred to a desk top 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, synchronising all tape recording times. 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 the use of a combination of ground based cameras and height data supplied as a function of time from the on-board radio or pressure altimeters.

In 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 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 synchronised 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 to maximise photograph image size but should 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 over estimates 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 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 either side of the vertical.

This method may be used to confirm that the helicopter follows a 6° ±0.5° glideslope within 10° of overhead the centre microphone as required by Annex 16, Volume 1, Chapter 8, paragraph 8.7.10 and 8.7.8.

Further, from the synchronised 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 Appendix 2 of Annex 16, Volume 1 (see 2.2.2). 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 the demonstration of overflight reference noise certification levels off-reference adjustments shall normally be made using a sensitivity curve of PNLTM versus advancing blade tip Mach number deduced from flyovers carried out at different airspeeds around the reference airspeed; however, the adjustment may be made 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 providing that the data cover a range of values of the noise correlating parameter agreed by the certificating authority between test and reference conditions. The advancing blade tip Mach number or agreed noise correlating parameter shall be computed from as measured data using true airspeed, onboard 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.

Each overflight noise test must be conducted such that:

a) The adjusted reference true air speed (V_{AR}) is the reference airspeed (V_R) specified in Section 8.6.3 of Chapter 8 of Annex 16, Volume 1, adjusted as necessary to produce the same main rotor advancing blade tip Mach number as associated with reference conditions;

Note: The reference advancing blade tip 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 reference speed (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 airspeed ((V$_{AR}$) is calculated from:

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

where c_T is speed of sound from the onboard measurement of outside air temperature (see Paragraph 6.7).

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; and

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.

d) The onboard outside static air temperature must be measured at the overflight height just prior to each flyover.

The calculation of noise levels, including the corrections, is the same as that described in Chapter 8 and Appendix 2 of Annex 16, Volume 1, except that the need for source noise adjustment is eliminated. It should be emphasised that in the determination of the duration correction (Δ2), 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) to synchronise 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 are required to be collected at relatively short time intervals, it may not be practicable to manually record the data and the use of one of the automatic systems listed as 5.1.2.2 b) to e) 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" deep shadow regions. To prevent reflections from the front of instruments it is recommended that light coloured equipment or clothing on the flight deck is avoided. Flight crews should be required to wear black or dark coloured clothing and gloves.

5.1.2.5 Further, 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" and 1" magnetic tapes with a 24 to 28 Volt DC power requirements. Six tape speeds and 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 using a hand held 35 mm 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 required to be photographed are within the field of view. Typical film cassettes containing about 2000 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 required 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 synchronisation of recorded data*

The need to synchronise 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 synchronisation 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 LED's 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. Confidence intervals of new data are statistically combined with the "flight datum" data to develop overall confidence intervals (see Appendix 1).

5.1.3.1 *Modifications or upgrades involving aerodynamic drag changes*

Use of drag devices, such as drag plates mounted beneath or on the sides of the "flight datum" helicopter, has proved to be effective in 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 realised 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 1, 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, in the case of a Chapter 8 certification, or flyover for the case of a Chapter 11 certification, are performed using the appropriate noise certification reference and test procedures;

c) A relationship of noise level versus change in aerodynamic drag or airspeed is developed using noise data, adjusted as specified in Appendix 2 or 4 of Annex 16, Volume 1, 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 c) above.

5.1.4 **Temperature and Relative Humidity Measurements**

5.1.4.1 Temperature and relative humidity measurements as defined in paragraph 2.2.3 of Appendix 2, Annex 16, Volume 1, are required 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 paragraph 8.3.1 of Appendix 2, Annex 16, Volume 1. The distances QK and Q_rK_r in the equations of paragraph 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 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 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 using the average of the temperature and relative humidity measured at 10 m (33 ft) and at the height associated with the PNLTM point in order to eliminate errors associated by 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 paragraph 8.3.1 of Appendix 2 of Annex 16, Volume 1, can be based on meteorological data measured at 10 m (33 ft) only.

5.1.4.4 Paragraph 2.2.2 of Appendix 2, Annex 16, Volume 1 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 paragraph 2.2 of ICAO Annex 16, Volume 1, Appendix 4, provided the test environment is within the temperature and relative humidity limits specified in paragraph 2.2 of ICAO Annex 16, Volume 1, Appendix 2. 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 SEL shall be corrected from the test values of temperature and humidity measured according to paragraph 2.2.2 of ICAO Annex 16, Volume 1, Appendix 4, to the reference conditions defined in paragraph 11.5.1.4 of ICAO Annex 16, Volume 1, Chapter 11. The correction procedure shall be similar to that defined in paragraph 8.3.1 of ICAO Annex 16, Volume 1, Appendix 2 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 the reference height, 150 m, respectively.

5.1.5 **Anomalous Test Conditions**

5.1.5.1 Annex 16, Volume 1, Appendix 2, Paragraph 2.2.2(f) requires that the tests be conducted under conditions that 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) using 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 (3.2°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 (400 ft) and 150 m (492 ft) depending on the flight condition and agreed with the certificating authority prior to the tests being conducted can be used.

5.1.5.3 If tests are adjusted using the “average” of the temperature and relative humidity measured at 10 m (33 ft) and the height association with the PNLTM point described in 5.1.4.4, the provisions of 5.1.5.1 do not apply. This is because 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.

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SECTION 6 - EVALUATION METHODS

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. This section 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) ambient noise levels both acoustic and electrical;

c) the establishment and extension of data bases;

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

e) integrated analysis of noise data;

f) computation of EPNL by the integrated method of adjustment; and

g) calculation of the speed of sound.

6.1 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 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 paragraph 4.3.1 of Appendix 2 of Annex 16, Volume 1, 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. However, the effect of these spectral irregularities are not normally removed from data from propeller-driven aeroplanes or helicopters since they are difficult to differentiate from engine and propeller or rotor associated tones.

6.2 AMBIENT NOISE LEVELS

Ambient 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 effective perceived noise level calculations. The effects of ambient noise may be removed by use of an approved procedure such as described in Appendix 3.

6.3 ESTABLISHMENT AND EXTENSION OF DATA BASES

6.3.1 Noise certification levels may be determined from a number of repeat noise measurements, at least six, at the same engine power (transmitted power for helicopters), height, speed and configuration at each of the reference noise measurement positions. The noise measurements are adjusted to reference conditions and the mean value and 90 per cent confidence interval obtained in accordance with Annex 16, Volume 1. As an alternative, aircraft may be flown over a range of noise correlating parameters (μ). In the case of aeroplanes the correlating parameter may be engine power setting and/or helical tip Mach number for propeller driven aeroplanes. For helicopters the parameter may be 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 (μ) at the appropriate reference μ.

6.3.2 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.

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

6.4 **TEST ENVIRONMENT CORRECTIONS**

6.4.1 The atmospheric conditions specified in Annex 16, Volume 1, section 2.2.2(b), (c), (d) and (e) of Appendix 2 require the measurement of ambient air temperature and relative humidity profiles during noise certification tests, 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.

6.4.2 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 section 2.2.2(b), (c), (d) and (e) of Annex 16, Volume 1, Appendix 2.

6.5 **INERTIAL NAVIGATION SYSTEMS FOR AEROPLANE FLIGHT PATH MEASUREMENT**

6.5.1 Criteria for the measurement of aeroplane height and lateral position relative to the intended track are described in section 2.3 of Appendix 2 of Annex 16 Volume 1. This section indicates that the method used should be independent of normal flight instrumentation. Since the development of this requirement, other tracking systems (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 regularly determined and the system calibrated. For this purpose ground based cameras can be used to determine the position of an aeroplane relative to them both laterally and in terms of height. The calibration should be undertaken sufficiently frequently to retain the accuracy specification of the system.

6.5.2 The accuracy of such systems must be acceptable to the certificating authority.

6.6 **COMPUTATION OF EPNL BY THE INTEGRATED METHOD OF ADJUSTMENT**

6.6.1 Section 9.1 of Annex 16, Appendix 2 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. The "integrated" adjustment method consists of applying all data adjustments to each measured set of sound pressure levels obtained at 0.5 s intervals to identify equivalent reference average sound pressure levels which are used to compute EPNL's 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 (θ) relative to the flight path and noise elevation angle (ψ) relative to the ground for both the measured (test) and corrected (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 minimised. The slight difference that will occur between test and reference elevation angle will have negligible effect on the corrected EPNL value.

6.6.2 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.

6.6.3 **Test aircraft position**

6.6.3.1 The "integrated" method for adjustment of measured noise-level data to reference conditions requires acoustic and aeroplane performance data at each 0.5 s time interval during the test flights. These data include aeroplane position relative to a three-dimensional (X, Y, Z) co-ordinate system, 1/3-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 is required for each flyover.

6.6.3.2 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 power reduction is used during the flyover measurement) and the time-correlated aeroplane-position data are used to determine time of overhead (t_{oh}), the test overhead height (h_{To})* , and the test minimum distance (d_{Tm}) from the test flight path to the microphone location ($K(X_{TM}, Y_{TM}, Z_{TM})$).

6.6.3.3 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 10 the minimum distance becomes:

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

Equation (1)

6.6.4 **Sound-propagation times and sound-emission angles**

6.6.4.1 The test sound propagation time (Δt_{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:

$$t_k = t_{ak} - \tfrac{1}{2} t_{Av}$$

Equation (2)

$$t_{ek} = t_k - \Delta t_{pk}$$

Equation (3)

$$\Delta t_{pk} = K_T Q_{ek} / c_T$$

Equation (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 Paragraph 6.7, where $T = (T_S + T_A)/2$).

6.6.4.2 Using the geometric relationships of Figure 11, the minimum distance 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:

$$\Delta t_{Tpk} = \left[1 \Big/ \left(c_T^{\,2} - V_T^{\,2}\right)\right] \times \left\{ BV_T^{\,2} + \left[\left(c_T^{\,2} - V_T^{\,2}\right)\left(d_{Tm}\right)^2 + \left(Bc_T V_T\right)^2\right]^{1/2} \right\}$$

Equation (5)

where V_T is the average true air speed of the test aeroplane along the flight path.

6.6.4.3 Similarly the test sound-emission angle is defined as:

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

$$\theta_{ek} = \sin^{-1}\left[d_{Tm} \Big/ \left(\Delta t_{Tpk}\right)\left(c_T\right)\right]$$

Equation (6)

6.6.5 **Aircraft reference flight path**

6.6.5.1 The geometry of the reference flight path is essentially similar to that shown in Figure 10, however, the following differences exist. The reference flight path is directly over the runway centerline (ie. Y_{DEV}=0). For the take off and approach flyovers, the measurement station is on the runway centerline (ie. $Y_{Rr}=Y_{rM}$); for lateral noise measurements, ($Y_{Rr}-Y_{rM}$) equals the reference lateral displacement of the measurement station.

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 co-ordinates as for the test location (K_T), ie. $\left(X_{TM}, Y_{TM}, Z_{TM}\right) = \left(X_{rM}, Y_{rM}, Z_{rM}\right)$.

6.6.5.2 The reference flight path may be geometrically specified relative to the

*For emphasis the subscript "T" is used here for test conditions. Annex 16 uses un-subscripted symbols for test conditions.

reference microphone location (K_r) by using the measurement station lateral distance, the height overhead (h_{ro}) and the flight path inclination angle (γ_r). These values are equated to the minimum distance (d_{rm}) from K_r by the following:

$$d_{rm} = \left[h_{ro}^{\,2} \cos^2 \gamma_r + \left(Y_{Rr} - Y_{rM} \right)^2 \right]^{1/2} \text{,or}$$

$$d_{rm} = \left[\left(X_{Rr} - X_{rM} \right)^2 + \left(Y_{Rr} - Y_{rM} \right)^2 + \left(Z_{Rr} - Z_{rM} \right)^2 \right]^{1/2}$$

Equation (7)

6.6.5.3 The basic acoustic assumption relating the test and reference flight conditions is that the three dimensional acoustic emission angles (θ_{ek} and θ_{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 by the equation:

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

Equation (8a)

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

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

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

Equation (8b)

6.6.6 **Time interval computation**

6.6.6.1 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} 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 11). The average time increment to be used in the EPNL computation is:

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

Equation (9)

where the reference time interval (Δt_{rk}) between data records is:

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

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

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

Equation (10)

6.6.6.2 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:

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

Equation (11)

6.6.7 **Adjusted effective perceived noise level**

After the sound pressure levels have been adjusted using Equation (8) the tone corrections are calculated following section 4.3 of Appendix 2, Annex 16 and using the noy weighting and the procedure for calculating perceived noise level (Section 4.2, Appendix 2, Annex 16) the reference PNLT's 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 combined to compute the adjusted EPNL as follows:

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

where the reference time (T_0) is 10 s and the summation is started by setting $\Delta t_{r(1-1)} = \Delta t_{r(2-1)}$ so that $\delta t_{r(1-1)} = \Delta t_{r1}$. The summation is terminated by assuming $\Delta t_{rn} = \Delta t_{r(n-1)}$ giving $\delta t_{rn} = \Delta t_{rn} = \Delta t_{r(n-1)}$.

6.7 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):

$$c = 343.2\left(T/T_0\right)^{1/2} \text{ metres / sec}$$

(i.e. $c = 1125.9\left(T/T_0\right)^{1/2}$ feet / sec)

where $T_0 = 293.15$ °K and T and the absolute ambient air temperature.

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SECTION 7 - MEASUREMENT AND ANALYSIS EQUIPMENT

Current technology noise recording and analysis equipment employing digital techniques which offer greater flexibility and precision than before are not catered for in the specification of equipment used in noise certification and described in Annex 16, Volume 1, Appendix 2, Section 3.

This section describes new instrumentation standards which have been approved by CAEP Working Group 1 to replace the existing Section 3 of Appendix 2 of Annex 16, Volume 1 and thereby enable the increasing use of digital instrumentation. This section will be removed from the Environmental Technical Manual when it is adopted into the Annex.

7.1 DEFINITIONS

For the purposes of this section the following definitions apply:

7.1.1 Measurement system

The combination of instruments used for the measurement of sound pressure levels, including a sound calibrator, windscreen, microphone system, signal recording and conditioning devices, and one-third octave band analysis system.

Note: Practical installations may include a number of microphone systems, the outputs from which are recorded simultaneously by a multi-channel recording/analysis device via signal conditioners as appropriate. For the purpose of this section, each complete measurement channel is considered to be a measurement system to which the requirements apply accordingly.

7.1.2 Microphone system:

The components of the measurement system which produce an electrical output signal in response to a sound pressure input signal, and which generally include a microphone, a preamplifier, extension cables, and other devices as necessary.

7.1.3 Sound incidence angle

In degrees, an angle between the principal axis of the microphone, as defined in IEC 61094-3[1] and IEC 61094-4[2], as amended and a line from the sound source to the centre of the diaphragm of the microphone.

Note: When the sound incidence angle is 0°, the sound is said to be received at the microphone at "normal (perpendicular) incidence"; when the sound incidence angle is 90°, the sound is said to be received at "grazing incidence".

7.1.4 Reference direction

In degrees, the direction of sound incidence specified by the manufacturer of the microphone, relative to a sound incidence angle of 0°, for which the free-field sensitivity level of the microphone system is within specified tolerance limits.

7.1.5 Free-field sensitivity of a microphone system

In volts per pascal, for a sinusoidal plane progressive sound wave of specified frequency, at a specified sound-incidence angle, the quotient of the root mean square voltage at the output of a microphone system and the root mean square sound pressure that would exist at the position of the microphone in its absence.

7.1.6 Free-field sensitivity level of a microphone system

In decibels, twenty times the logarithm to the base ten of the ratio of the free-field sensitivity of a microphone system and the reference sensitivity of one volt per pascal.

Note: The free-field sensitivity level of a microphone system may be determined by

[1] IEC 61094-3: 1995 entitled “Measurement microphones – Part 3: Primary method for free-field calibration of laboratory standard microphones by the reciprocity technique”

[2] IEC 61094-4: 1995 entitled “Measurement microphones – Part 4: Specifications for working standard microphones” These IEC publications may be obtained from the Bureau central de la Commission électrotechnique internationale, 1 rue de Varembé, Geneva, Switzerland

subtracting the sound pressure level (in decibels re 20 mPa) of the sound incident on the microphone from the voltage level (in decibels re 1 V) at the output of the microphone system, and adding 93.98 dB to the result.

7.1.7 **Time-average band sound pressure level**

In decibels, ten times the logarithm to the base ten, of the ratio of the time mean square of the instantaneous sound pressure during a stated time interval and in a specified one-third octave band, to the square of the reference sound pressure of 20μPa.

7.1.8 **Level range**

In decibels, an operating range determined by the setting of the controls that are provided in a measurement system for the recording and one-third octave band analysis of a sound pressure signal. The upper boundary associated with any particular level range shall be rounded to the nearest decibel.

7.1.9 **Calibration sound pressure level**

In decibels, the sound pressure level produced, under reference environmental conditions, in the cavity of the coupler of the sound calibrator that is used to determine the overall acoustical sensitivity of a measurement system.

7.1.10 **Reference level range**

In decibels, the level range for determining the acoustical sensitivity of the measurement system and containing the calibration sound pressure level.

7.1.11 **Calibration check frequency**

In hertz, the nominal frequency of the sinusoidal sound pressure signal produced by the sound calibrator.

7.1.12 **Level difference**

In decibels, for any nominal one-third octave midband frequency, the output signal level measured on any level range minus the level of the corresponding electrical input signal.

7.1.13 **Reference level difference**

In decibels, for a stated frequency, the level difference measured on a level range for an electrical input signal corresponding to the calibration sound pressure level, adjusted as appropriate, for the level range.

7.1.14 **Level non-linearity**

In decibels, the level difference measured on any level range, at a stated one-third octave nominal midband frequency, minus the corresponding reference level difference, all input and output signals being relative to the same reference quantity.

7.1.15 **Linear operating range**

In decibels, for a stated level range and frequency, the range of levels of steady sinusoidal electrical signals applied to the input of the entire measurement system, exclusive of the microphone but including the microphone preamplifier and any other signal-conditioning elements that are considered to be part of the microphone system, extending from a lower to an upper boundary, over which the level non-linearity is within specified tolerance limits.

Note: It is not necessary to include microphone extension cables as configured in the field.

7.1.16 **Windscreen insertion loss**

In decibels, at a stated nominal one-third octave midband frequency, and for a stated sound incidence angle on the inserted microphone, the indicated sound pressure level without the windscreen installed around the microphone minus the sound pressure level with the windscreen installed.

7.2 REFERENCE ENVIRONMENTAL CONDITIONS

7.2.1 The reference environmental conditions for specifying the performance of a measurement system are:

- air temperature 23°C
- static air pressure 101.325 kPa
- relative humidity 50 %

7.3 **GENERAL**

Note Measurements of aircraft noise that utilise instruments that conform to the specifications of *this section yield one-third octave band sound pressure levels as a function of time, for the calculation of effective perceived noise level as described in Annex 16, Volume 1, Appendix 2, Section 4.*

7.3.1 The measurement system shall consist of equipment approved by the certificating authority and equivalent to the following:

a) a windscreen (see 7.4);

b) a microphone system (see 7.5);

c) a recording and reproducing system to store the measured aircraft noise signals for subsequent analysis (see 7.6);

d) a one-third octave band analysis system (see 7.7); and

e) calibration systems to maintain the acoustical sensitivity of the above systems within specified tolerance limits (see 7.8).

7.3.2 For any component of the measurement system that converts an analog signal to digital form, such conversion shall be performed so that the levels of any possible aliases or artefacts of the digitisation process will be less than the upper boundary of the linear operating range by at least 50 dB at any frequency less than 12.5 kHz. The sampling rate shall be at least 28 kHz. An anti-aliasing filter shall be included before the digitisation process.

7.4 **WINDSCREEN**

7.4.1 In the absence of wind and for sinusoidal sounds at grazing incidence, the insertion loss caused by the windscreen of a stated type installed around the microphone shall not exceed ±1.5 dB at nominal one-third octave midband frequencies from 50 Hz to 10 kHz inclusive.

7.5 **MICROPHONE SYSTEM**

7.5.1 The microphone system shall conform to the specifications in 7.5.2 to 7.5.4. Various microphone systems may be approved by the certificating authority on the basis of demonstrated equivalent overall electroacoustical performance. Where two or more microphone systems of the same type are used, demonstration that at least one system conforms to the specifications in full is sufficient to demonstrate conformance.

Note: This demonstration of equivalent performance does not eliminate the need to calibrate and check each system as defined in 7.9.

7.5.2 The microphone shall be mounted with the sensing element 1.2 m (4 ft) above the local ground surface and shall be oriented for grazing incidence, i.e., with the sensing element substantially in the plane defined by the predicted reference flight path of the aircraft and the measuring station. The microphone mounting arrangement shall minimise the interference of the supports with the sound to be measured. Figure 12 illustrates sound incidence angles on a microphone.

7.5.3 The free-field sensitivity level of the microphone and preamplifier in the reference direction, at frequencies over at least the range of one-third-octave nominal midband frequencies from 50 Hz to 5 kHz inclusive, shall be within ±1.0 dB of that at the calibration check frequency, and within ±2.0 dB for nominal midband frequencies of 6.3 kHz, 8 kHz and 10 kHz.

7.5.4 For sinusoidal sound waves at each one-third octave nominal midband frequency over the range from 50 Hz to 10 kHz inclusive, the free-field sensitivity levels of the microphone system at sound incidence angles of 30°, 60°, 90°, 120° and 150°, shall not differ from the free-field sensitivity level at a sound incidence angle of 0° ("normal incidence") by more than the values shown in Table 7-1. The free-field sensitivity level differences at sound incidence angles between any two adjacent sound incidence angles in Table 7-1 shall not exceed the tolerance limit for the greater angle.

Nominal midband frequency kHz	Maximum difference between the free-field sensitivity level of a microphone system at normal incidence and the free-field sensitivity level at specified sound incidence angles dB — Sound Incidence angle degrees				
	30	60	90	120	150
0.05 to 1.6	0.5	0.5	1.0	1.0	1.0
2.0	0.5	0.5	1.0	1.0	1.0
2.5	0.5	0.5	1.0	1.5	1.5
3.15	0.5	1.0	1.5	2.0	2.0
4.0	0.5	1.0	2.0	2.5	2.5
5.0	0.5	1.5	2.5	3.0	3.0
6.3	1.0	2.0	3.0	4.0	4.0
8.0	1.5	2.5	4.0	5.5	5.5
10.0	2.0	3.5	5.5	6.5	7.5

Table 7-1 Microphone Directional Response Requirements

7.6 RECORDING AND REPRODUCING SYSTEMS

7.6.1 A recording and reproducing system, such as a digital or analogue magnetic tape recorder, a computer-based system or other permanent data storage device, shall be used to store sound pressure signals for subsequent analysis. The sound produced by the aircraft shall be recorded in such a way that a record of the complete acoustical signal is retained. The recording and reproducing systems shall conform to the specifications in 7.6.2 to 7.6.9 at the recording speeds and/or data sampling rates used for the noise certification tests. Conformance shall be demonstrated for the frequency bandwidths and recording channels selected for the tests.

7.6.2 The recording and reproducing systems shall be calibrated as described in 7.9.

Note: For aircraft noise signals for which the high frequency spectral levels decrease rapidly with increasing frequency, appropriate pre-emphasis and complementary de-emphasis networks may be included in the measurement system. If pre-emphasis is included, over the range of nominal one-third octave midband frequencies from 800 Hz to 10 kHz inclusive, the electrical gain provided by the pre-emphasis network shall not exceed 20 dB relative to the gain at 800 Hz.

7.6.3 For steady sinusoidal electrical signals applied to the input of the entire measurement system exclusive of the microphone system, but including the microphone preamplifier, and any other signal-conditioning elements that are considered to be part of the microphone system, at a selected signal level within 5 dB of that corresponding to the calibration sound pressure level on the reference level range, the time average signal level indicated by the readout device at any one-third octave nominal midband frequency from 50 Hz to10 kHz inclusive shall be within ±1.5 dB of that at the calibration check frequency. The frequency response of a measurement system, which includes components that convert analogue signals to digital form, shall be within ±0.3 dB of the response at 10 kHz over the frequency range from 10 kHz to 11.2 kHz.

Note: It is not necessary to include microphone extension cables as configured in the field.

7.6.4 For analogue tape recordings, the amplitude fluctuations of a 1 kHz sinusoidal signal recorded within 5 dB of the level corresponding to the calibration sound pressure level shall not vary by more than ±0.5 dB throughout any reel of the type of magnetic tape utilised. Conformance to this requirement shall be demonstrated using a device which has time-averaging properties equivalent to those of the spectrum analyser.

7.6.5 For all appropriate level ranges and for steady sinusoidal electrical signals applied to the input of the measurement system exclusive of the microphone system, but including the microphone preamplifier, and any other signal-conditioning elements that are considered to be part of the microphone system, at one-third-octave nominal midband frequencies of 50 Hz, 1 kHz and 10 kHz, and the calibration check frequency, if it is not one of these frequencies, the level non-linearity shall not exceed ±0.5 dB for a linear operating range of at least 50 dB below the upper boundary of the level range.

Note 1: Level linearity of measurement system components should be tested according to the methods described in IEC 61265[3] *as amended.*

Note 2: It is not necessary to include microphone extension cables as configured in the field.

7.6.6 On the reference level range, the level corresponding to the calibration sound pressure level shall be at least 5 dB, but no more than 30 dB less than the upper boundary of the level range.

7.6.7 The linear operating ranges on adjacent level ranges shall overlap by at least 50 dB minus the change in attenuation introduced by a change in the level range controls.

Note: It is possible for a measurement system to have level range controls that permit attenuation changes of either 10 dB or 1 dB, for example. With 10 dB steps, the minimum overlap required would be 40 dB, and with 1 dB steps the minimum overlap would be 49 dB.

7.6.8 Provision shall be made for an overload indication to occur during an overload condition on any relevant level range.

7.6.9 Attenuators included in the measurement system to permit range changes shall operate in known intervals of decibel steps.

7.7 ANALYSIS SYSTEMS

7.7.1 The analysis system shall conform to the specifications in 7.7.2 to 7.7.7 for the frequency bandwidths, channel configurations and gain settings used for analysis.

7.7.2 The output of the analysis system shall consist of one-third octave band sound pressure levels as a function of time, obtained by processing the noise signals (preferably recorded) through an analysis system with the following characteristics:

a) a set of 24 one-third octave band filters, or their equivalent, having nominal midband frequencies from 50 Hz to 10 kHz inclusive;

b) response and averaging properties in which, in principle, the output from any one-third octave filter band is squared, averaged and displayed or stored as time averaged sound pressure levels;

c) the interval between successive sound-pressure level samples shall be 500 ms ±5 ms for spectral analysis with or without SLOW time weighting;

d) for those analysis systems that do not process the sound-pressure signals during the period of time required for readout and / or resetting of the analyser, the loss of data shall not exceed a duration of 5 ms; and

e) the analysis system shall operate in real time from 50 Hz to at least 12 kHz inclusive. This requirement applies to all operating channels of a multi-channel spectral analysis system.

7.7.3 The one-third octave band analysis system shall at least conform to the class 2 electrical performance requirements of IEC

[3] IEC 61265: 1995 entitled "Instruments for measurement of aircraft noise – Performance requirements for systems to measure one-third-octave band sound pressure levels in noise certification of transport-category aeroplanes". This IEC publications may be obtained from the Bureau central de la Commission électrotechnique internationale, 1 rue de Varembé, Geneva, Switzerland

61260[4] as amended, over the range of one-third octave nominal midband frequencies from 50 Hz to 10 kHz inclusive.

Note: Tests of the one-third octave band analysis system should be made according to the methods described in IEC 612604 or by an equivalent procedure approved by the certificating authority, for relative attenuation, anti-aliasing filters, real time operation, level linearity, and filter integrated response (effective bandwidth).

7.7.4 When SLOW time averaging is performed in the analyser, the response of the one-third octave band analysis system to a sudden onset or interruption of a constant sinusoidal signal at the respective one-third octave nominal midband frequency shall be measured at sampling instants 0.5, 1, 1.5 and 2 s after the onset and 0.5 and 1 s after interruption. The rising response shall be -4 ± 1 dB at 0.5 s, -1.75 ± 0.75 dB at 1 s, -1 ± 0.5 dB at 1.5 s and -0.5 ± 0.5 dB at 2 s relative to the steady-state level. The falling response shall be such that the sum of the output signal levels, relative to the initial steady-state level, and the corresponding rising response reading is -6.5 ± 1 dB, at both 0.5 and 1 s. At subsequent times the sum of the rising and falling responses shall be -7.5 dB or less. This equates to an exponential averaging process (SLOW weighting) with a nominal 1 s time constant (i.e. 2 s averaging time).

7.7.5 When the one-third octave band sound pressure levels are determined from the output of the analyser without SLOW time weighting, SLOW time weighting shall be simulated in the subsequent processing. Simulated SLOW weighted sound pressure levels can be obtained using a continuous exponential averaging process by the following equation:

$$L_S(i,k) = 10\log\left[(0.60653)10^{0.1L_S[i,(k-1)]} + (0.39347)10^{0.1L(i,k)}\right]$$

where $L_s(i,k)$ is the simulated SLOW weighted sound pressure level and $L(i,k)$ is the as-measured 0.5 s time average sound pressure level determined from the output of the analyser for the k-th instant of time and the i-th one-third octave band. For k =1, the SLOW weighted sound pressure $L_s[i,(k\text{-}1\text{=}0)]$ on the right hand side should be set to 0 dB.

An approximation of the continuous exponential averaging is represented by the following equation for a four sample averaging process for $k \geq 4$:

$$L_s(i,k) = 10\log\left[\begin{array}{r}(0.13)10^{0.1L[i,(k-3)]} + (0.21)10^{0.1L[i,(k-2)]} + \\ (0.27)10^{0.1L[i,(k-1)]} + (0.39)10^{0.1L[i,k]}\end{array}\right]$$

where $L_s(i,k)$ is the simulated SLOW weighted sound pressure level and $L(i,k)$ is the as measured 0.5 s time average sound pressure level determined from the output of the analyser for the k-th instant of time and the i-th one-third octave band.

The sum of the weighting factors is 1.0 in the two equations. Sound pressure levels calculated by means of either equation are valid for the sixth and subsequent 0.5 s data samples, or for times greater than 2.5 s after initiation of data analysis.

Note: The coefficients in the two equations were calculated for use in determining equivalent SLOW weighted sound pressure levels from samples of 0.5 s time average sound pressure levels. The equations should not be used with data samples where the averaging time differs from 0.5 s.

7.7.6 The instant in time by which a SLOW time weighted sound pressure level is characterised shall be 0.75 s earlier than the actual readout time.

Note: The definition of this instant in time is required to correlate the recorded noise with the aircraft position when the noise was emitted and takes into account the averaging period of the SLOW weighting. For each ½ second data record this instant in time may also be identified as 1.25 seconds after the start of the associated 2 second averaging period.

7.7.7 The resolution of the sound pressure levels, both displayed and stored, shall be 0.1 dB or better.

[4] IEC 61260: 1995 entitled " Electroacoustics – Octave-band and fractional-octave-band filters". This IEC publications may be obtained from the Bureau central de la Commission électrotechnique internationale, 1 rue de Varembé, Geneva, Switzerland

7.8 CALIBRATION SYSTEMS

7.8.1 The acoustical sensitivity of the measurement system shall be determined using a sound calibrator generating a known sound pressure level at a known frequency. The sound calibrator shall at least conform to the class 1L requirements of IEC 60942[5] as amended.

7.9 CALIBRATION AND CHECKING OF SYSTEM

7.9.1 Calibration and checking of the measurement system and its constituent components shall be carried out to the satisfaction of the certificating authorities by the methods specified in 7.9.2 to 7.9.10. The calibration adjustments, including those for environmental effects on sound calibrator output level, shall be reported to the certificating authority and applied to the measured one-third-octave sound pressure levels determined from the output of the analyzer. Data collected during an overload indication are invalid and shall not be used. If the overload condition occurred during recording, the associated test data shall be considered as invalid, whereas if the overload occurred during analysis the analysis shall be repeated with reduced sensitivity to eliminate the overload.

7.9.2 The free field frequency response of the microphone system may be determined by use of an electrostatic actuator in combination with manufacturer's data or by tests in an anechoic free-field facility. The correction for frequency response shall be determined within 90 days of each test series. The correction for non-uniform frequency response of the microphone system shall be reported to the certificating authority and applied to the measured one-third octave band sound pressure levels determined from the output of the analyser.

7.9.3 When the angles of incidence of sound emitted from the aircraft are within ±30° of grazing incidence at the microphone (see Figure 12), a single set of free-field corrections based on grazing incidence is considered sufficient for correction of directional response effects. For other cases, the angle of incidence for each ½ second sample shall be determined and applied for the correction of incidence effects.

7.9.4 For analogue magnetic tape recorders, each reel of magnetic tape shall carry at least 30 seconds of pink random or pseudo-random noise at its beginning and end. Data obtained from analogue tape-recorded signals shall be accepted as reliable only if level differences in the 10 kHz one-third-octave-band are not more than 0.75 dB for the signals recorded at the beginning and end.

7.9.5 The frequency response of the entire measurement system while deployed in the field during the test series, exclusive of the microphone, shall be determined at a level within 5 dB of the level corresponding to the calibration sound pressure level on the level range used during the tests for each one-third octave nominal midband frequency from50 Hz to10 kHz inclusive, utilising pink random or pseudo-random noise. The output of the noise generator shall be determined by a method traceable to a national standards laboratory within 6 months of each test series and tolerable changes in the relative output from the previous calibration at each one-third octave band shall be not more than 0.2 dB. The correction for frequency response shall be reported to the certificating authority and applied to the measured one-third octave sound pressure levels determined from the output of the analyser.

7.9.6 The performance of switched attenuators in the equipment used during noise certification measurements and calibration shall be checked within six months of each test series to ensure that the maximum error does not exceed 0.1 dB.

7.9.7 The sound pressure level produced in the cavity of the coupler of the sound calibrator shall be calculated for the test environmental conditions using the manufacturer's supplied information on the influence of atmospheric air pressure and temperature. The sound pressure level shall be used to establish the acoustical sensitivity of the measurement system. The output of the sound calibrator shall be determined by a method traceable to a national standards laboratory within 6 months of each test series

[5] IEC 60942: 1997 entitled " Electroacoustics - Sound calibrators". This IEC publications may be obtained from the Bureau central de la Commission électrotechnique internationale, 1 rue de Varembé, Geneva, Switzerland

and tolerable changes in output from the previous calibration shall be not more than 0.2 dB.

7.9.8 Sufficient sound pressure level calibrations shall be made during each test day to ensure that the acoustical sensitivity of the measurement system is known at the prevailing environmental conditions corresponding with each test series. The measurement system shall be considered satisfactory if the difference is not greater than 0.5 dB between the acoustical sensitivity levels recorded immediately before and immediately after each test series on a given day. The 0.5 dB limit applies after any atmospheric pressure corrections have been determined for the calibrator output level. The arithmetic mean of the before and after measurements shall be used to represent the acoustical sensitivity level of the measurement system for that test series. The calibration corrections shall be reported to the certificating authority and applied to the measured one-third octave band sound pressure levels determined from the output of the analyser.

7.9.9 Each recording medium, such as a reel, cartridge, cassette, or diskette, shall carry a sound pressure level calibration of at least 10 seconds duration at its beginning and end.

7.9.10 The free-field insertion loss of the windscreen for each one-third octave nominal midband frequency from 50 Hz to 10 kHz inclusive shall be determined with sinusoidal sound signals at appropriate incidence angles on the inserted microphone. For a windscreen which is undamaged and uncontaminated the insertion loss may be taken from manufacturer’s data. In addition the insertion loss of the windscreen may be determined by a method traceable to a national standards laboratory within 6 months of each test series and tolerable changes in the insertion loss from the previous calibration at each one-third-octave frequency band shall be not more than 0.4 dB. The correction for the free-field insertion loss of the windscreen shall be reported to the certificating authority and applied to the measured one-third octave sound pressure levels determined from the output of the analyser.

7.10 ADJUSTMENTS FOR AMBIENT NOISE

7.10.1 The ambient noise, including both acoustical background and electrical noise of the measurement system, shall be recorded for at least 10s at the measurement points with the system gain set at the levels used for the aircraft noise measurements, at appropriate times during each test day. The ambient noise shall be representative of the acoustical background that exits during the flyover test run. The recorded aircraft noise data shall be accepted only if the ambient noise levels when analysed in the same way and quoted in PNL (see Paragraph 4.1.3(a) of Appendix 2, Annex 16, Volume 1) are at least 20 dB below the maximum PNL of the aircraft.

7.10.2 Aircraft sound pressure levels within the 10 dB-down points (see Paragraph 4.5.1 of Appendix 2, Annex 16, Volume 1) shall exceed the mean ambient noise levels determined above by at least 3 dB in each one-third octave band or be adjusted using the method described in Appendix 3.

SECTION 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 utilising "static-to-flight equivalencies (SFE's)".

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 critical computer programs to be tracked 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, control procedures, design description and verification process are described below.

8.2 SOFTWARE CONTROL PLAN

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 data base.

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 documenting modifications to the baseline case that result from program coding changes. Review and auditing procedures will be established within the verification process that 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 procedure for the SFE software system, or modifications to it, shall include a process to verify that the calculations described in the documentation are being properly performed by the software. The process may include hand 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.

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SECTION 9 - GUIDELINES FOR NOISE CERTIFICATION OF TILTROTOR AIRCRAFT

Guidelines have been developed for the noise certification of tiltrotor aircraft. These are presented as Attachment YY to ICAO Annex 16, Volume 1. To help in the understanding of these guidelines and to assist in their application background information is presented in Appendix 6.

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REFERENCES

1. Jet mixing noise: comparison of measurement and theory.
   B.J. Tester and V.M. Szewczyk, AIAA Paper 79-0570.

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

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

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

5. SAE ARP 876D: 1993 Gas Turbine Jet Exhaust Noise Prediction.

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

7. SAE AIR 1846-1984: Measurement of Noise from Gas Turbine Engines During Static Operation.

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

9. ESDU Item 80038, Amendment A: The Correction of Measured Noise Spectra for the effects of Ground Reflection.

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

NOTE 2: SAE AIR's and ARP's may be obtained from the Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, PA 15096, United States of America.

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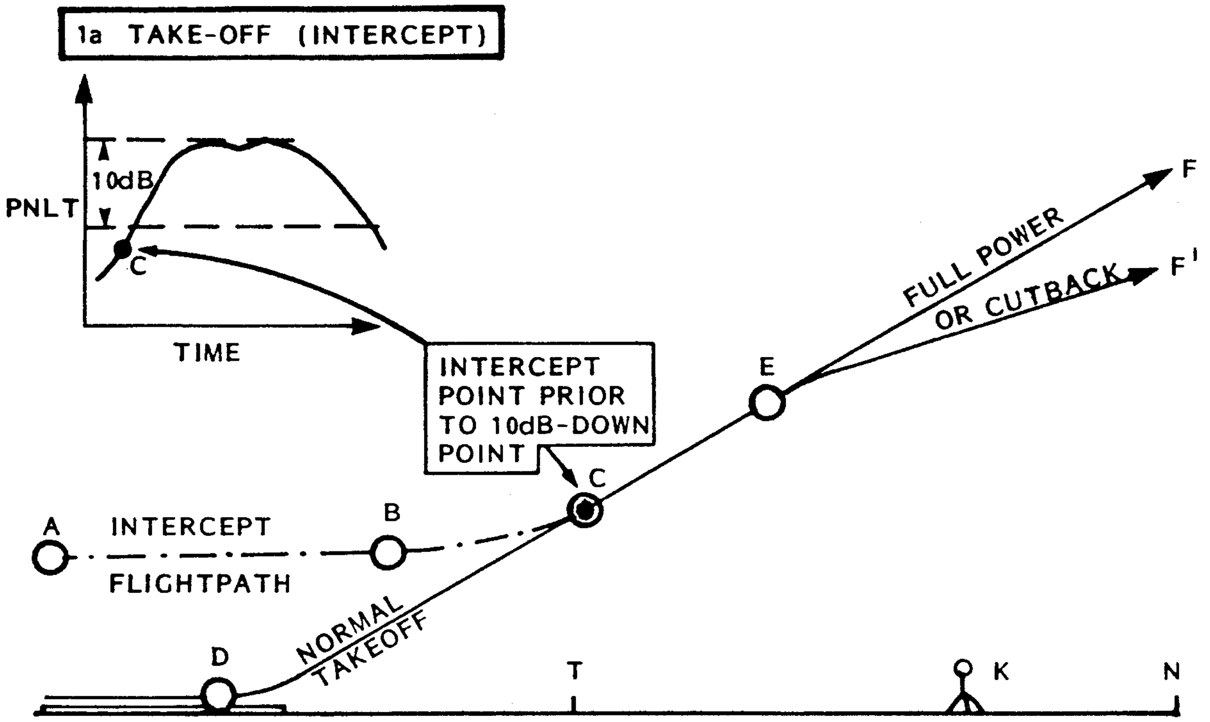


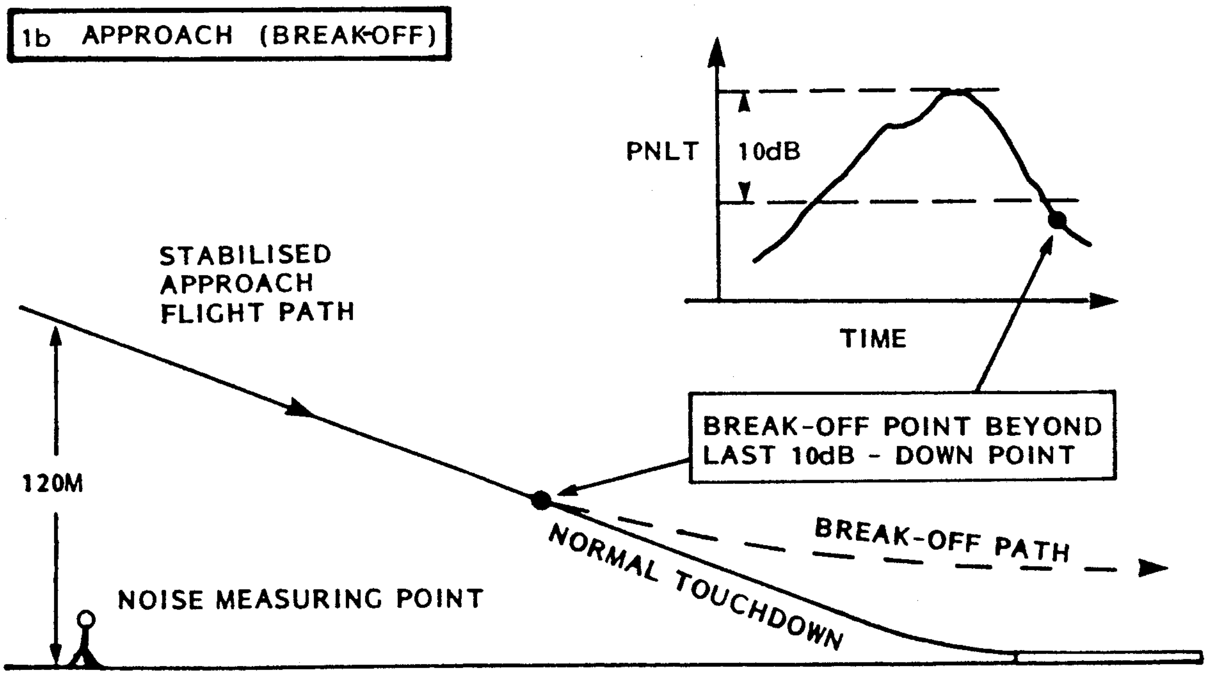


Figure 1 Flight Path Intercept Procedures

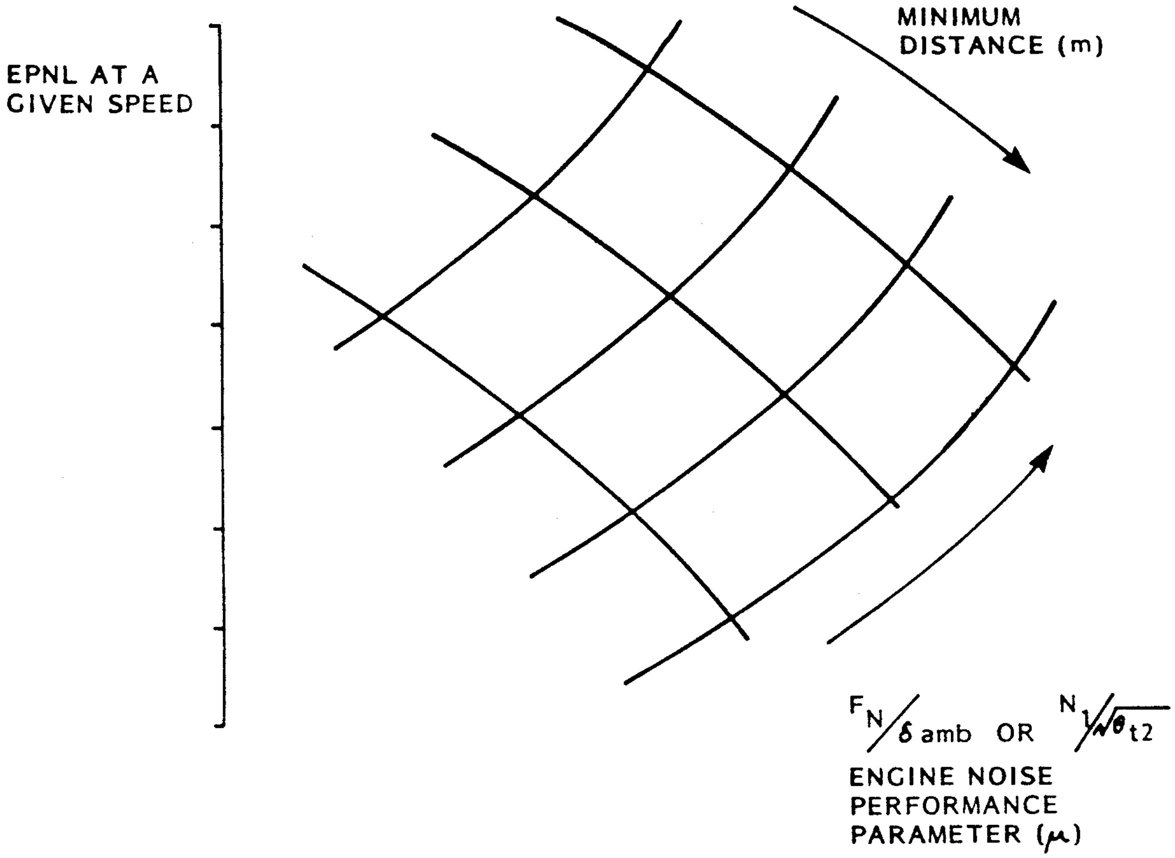


FIGURE 2

Form of NPD plot for turbo-jet or turbo-fan powered aeroplanes

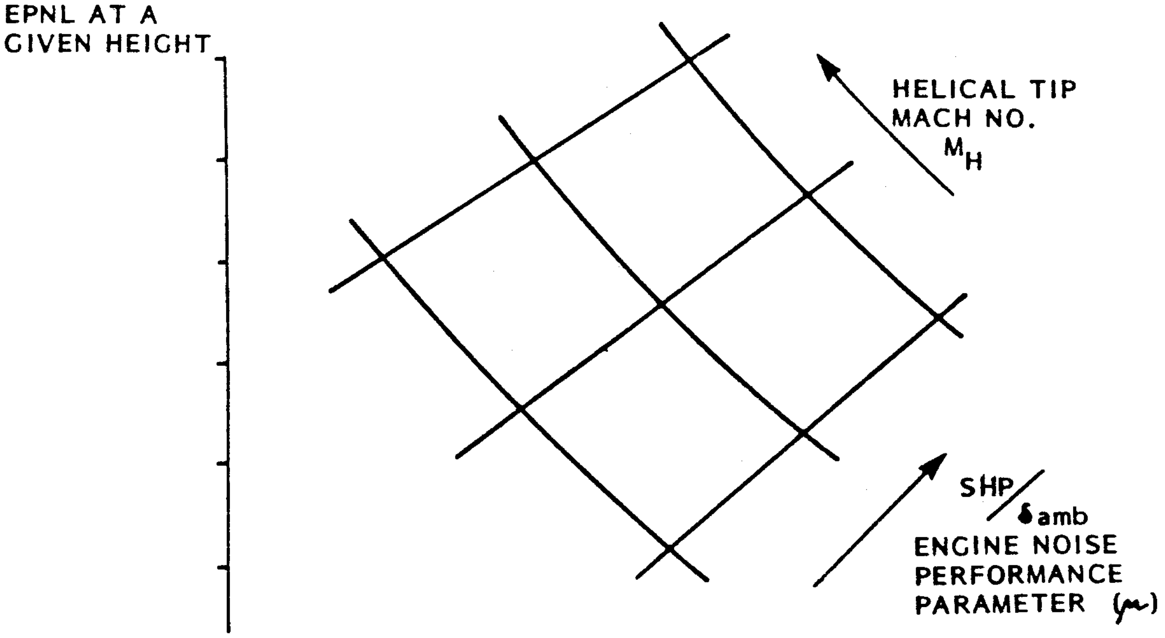


FIGURE 3

Form of NPD plot for propeller driven heavy aeroplanes

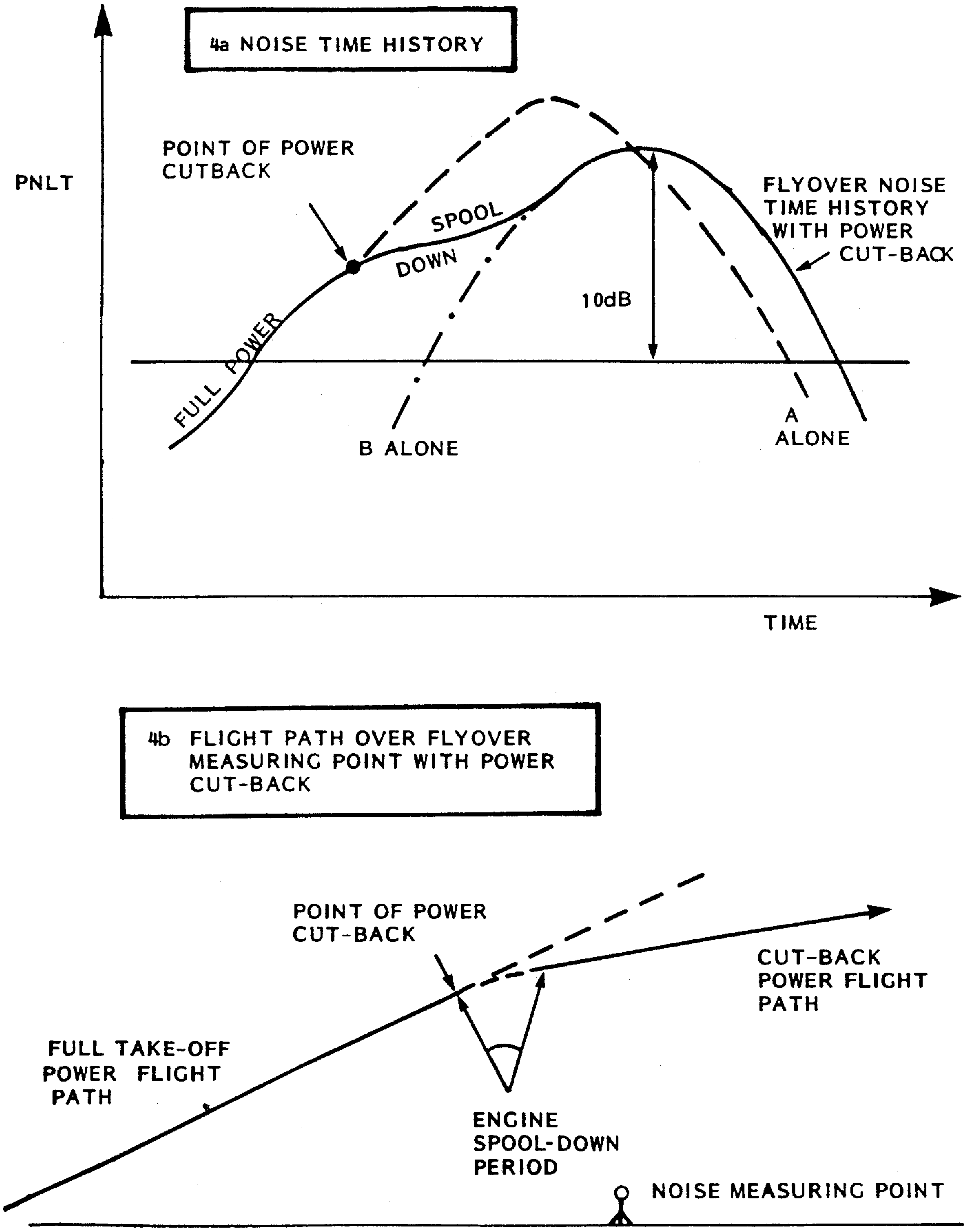
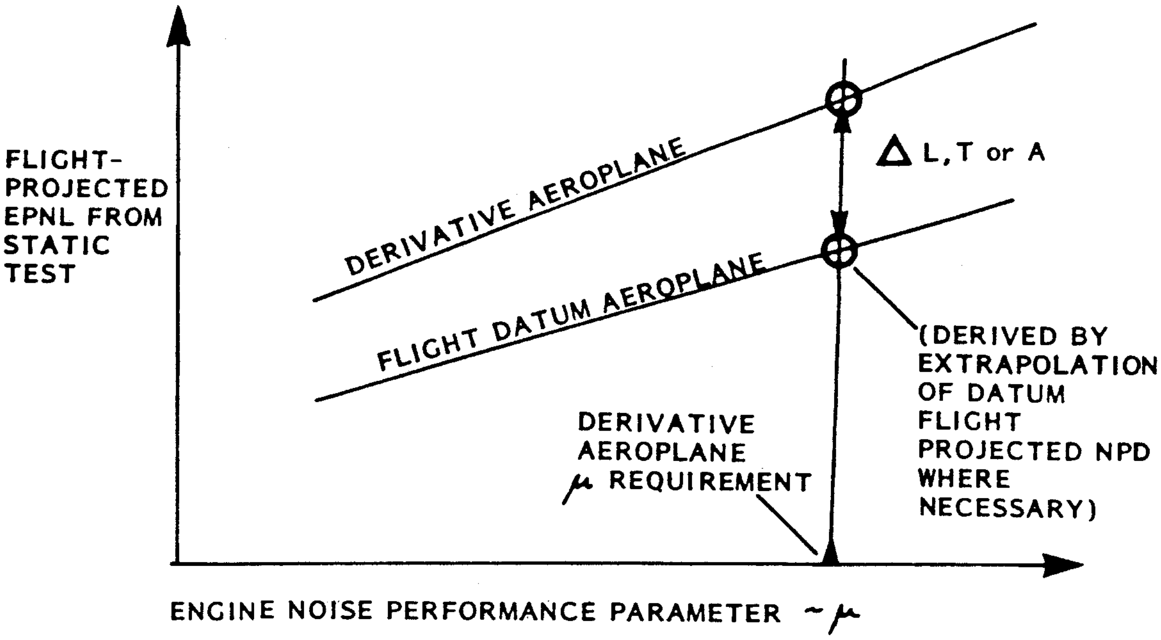


FIGURE 4

Computation of cutback-takeoff noise level from constant power tests



DEFINITIONS

Δ_L = DIFFERENCE BETWEEN FLIGHT DATUM AND DERIVATIVE AEROPLANE EPNL AT THE POWER REQUIREMENT OF THE DERIVATIVE AEROPLANE AT THE LATERAL CONDITION

Δ_T = DIFFERENCE BETWEEN FLIGHT DATUM AND DERIVATIVE AEROPLANE EPNL AT THE POWER REQUIREMENT AND ALTITUDE OF THE DERIVATIVE AEROPLANE AT THE TAKE-OFF CONDITION.

Δ_A = DIFFERENCE BETWEEN FLIGHT DATUM AND DERIVATIVE AEROPLANE EPNL AT THE POWER REQUIREMENT OF THE DERIVATIVE AEROPLANE AT THE APPROACH CONDITION.

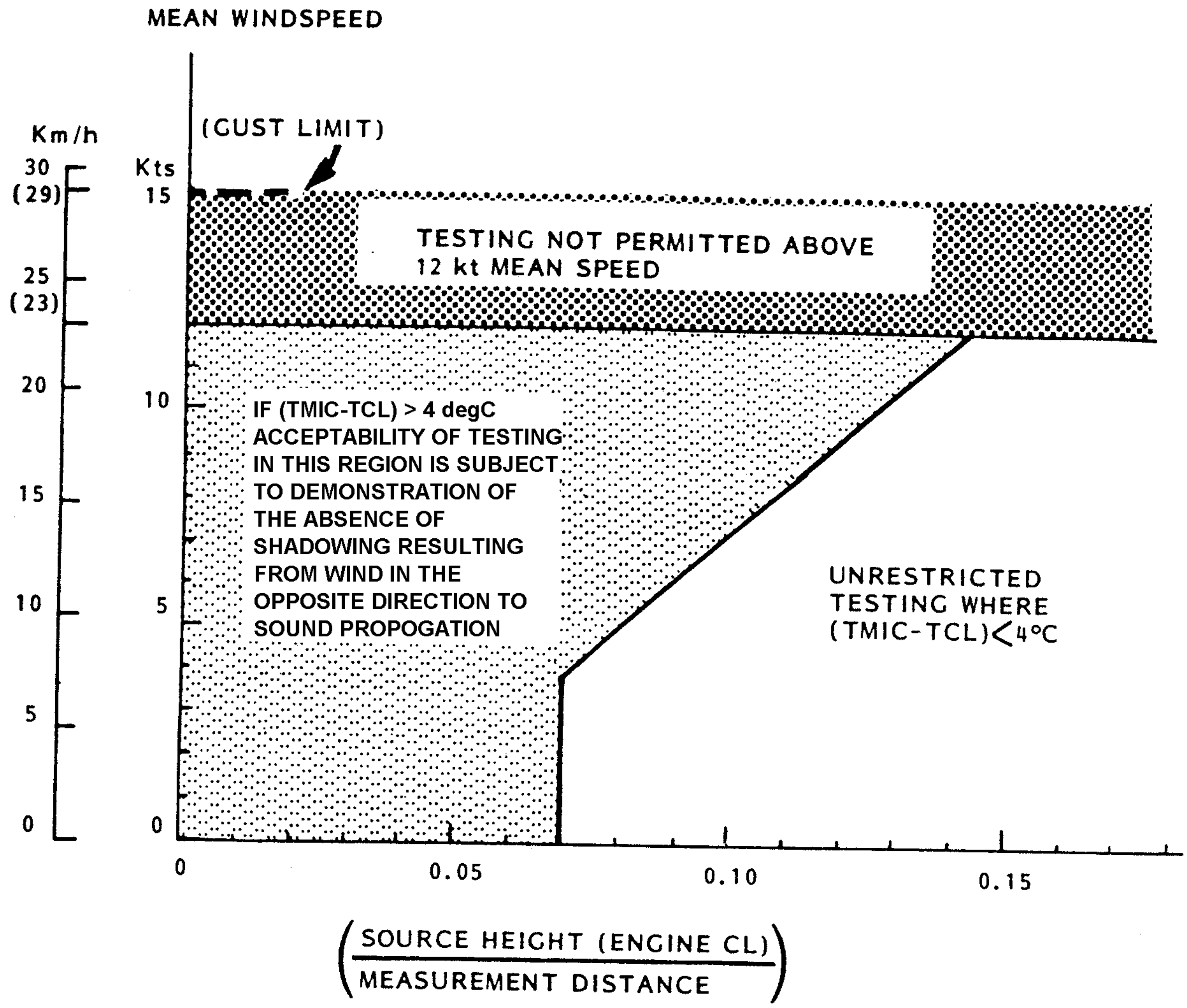
LIMITATIONS

(i) $|\Delta_L| + |\Delta_T| + |\Delta_A|$ SHALL NOT EXCEED 5 EPNdB

(ii) Δ_L, Δ_T or Δ_A SHALL NOT EXCEED ±3 EPNdB INDIVIDUALLY.

FIGURE 5

Limitation on the use of static test where no validating flight test data exist



NOTE

TCL = TEMPERATURE AT ENGINE CENTRELINE HEIGHT

TMIC = TEMPERATURE WITHIN ±5MM OF GROUND MICROPHONE DIAPHRAGM HEIGHT

FIGURE 6

Weather criteria for use with ground microphone installations

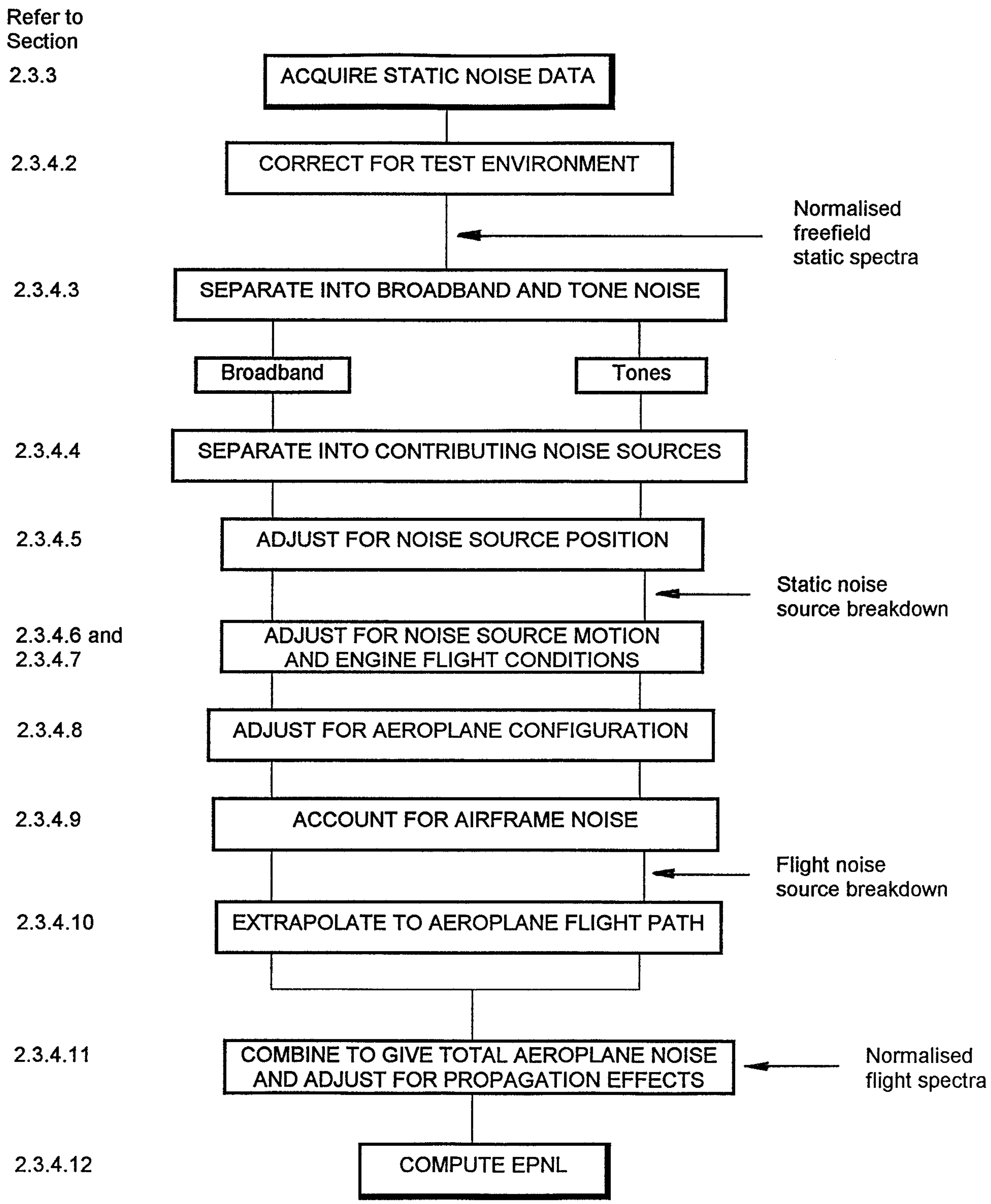


Figure 7
Generalised projection of static engine data to aeroplane flight conditions

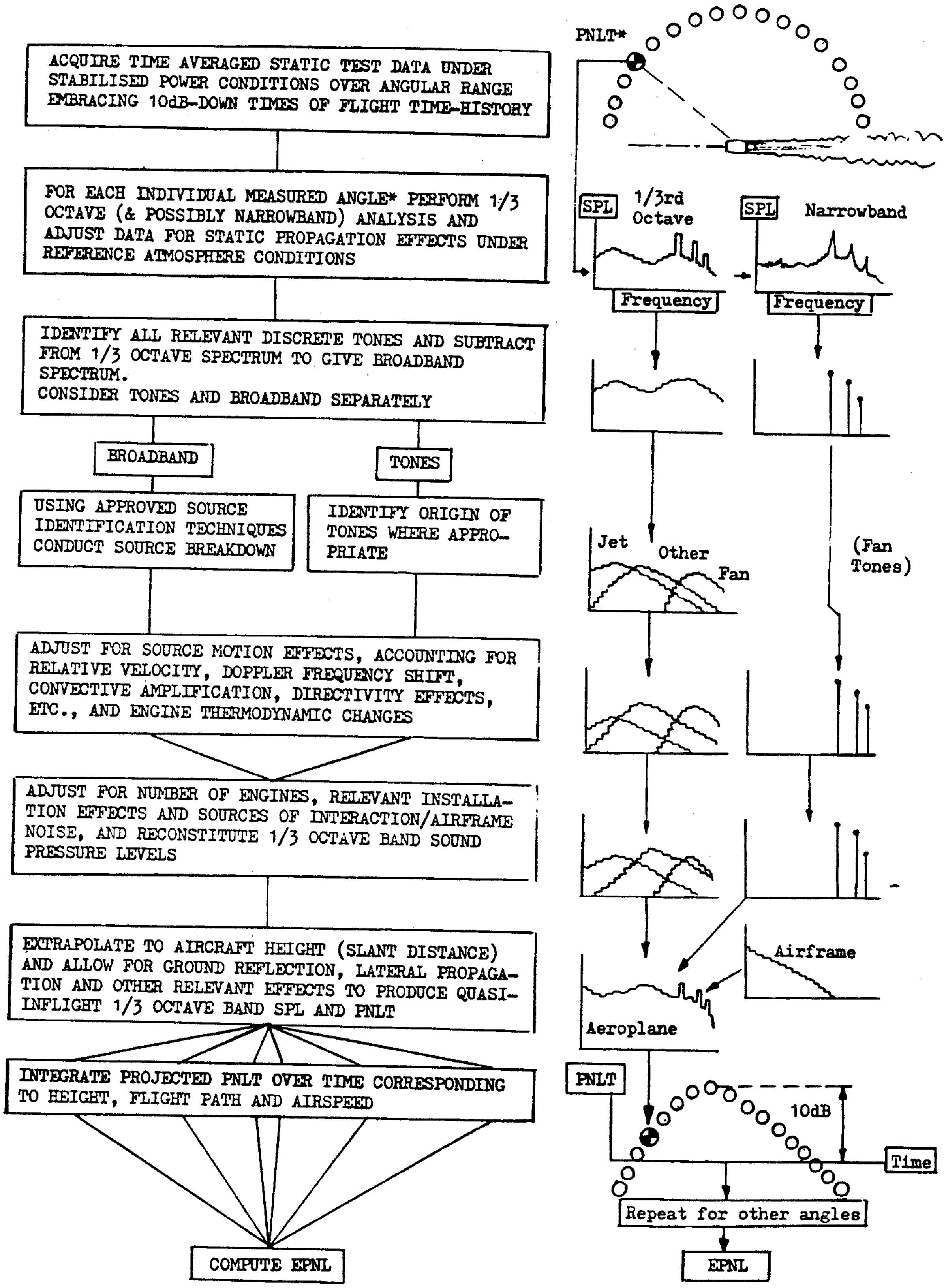


Figure 8
Example procedure for projection of static engine data to aeroplane flight conditions

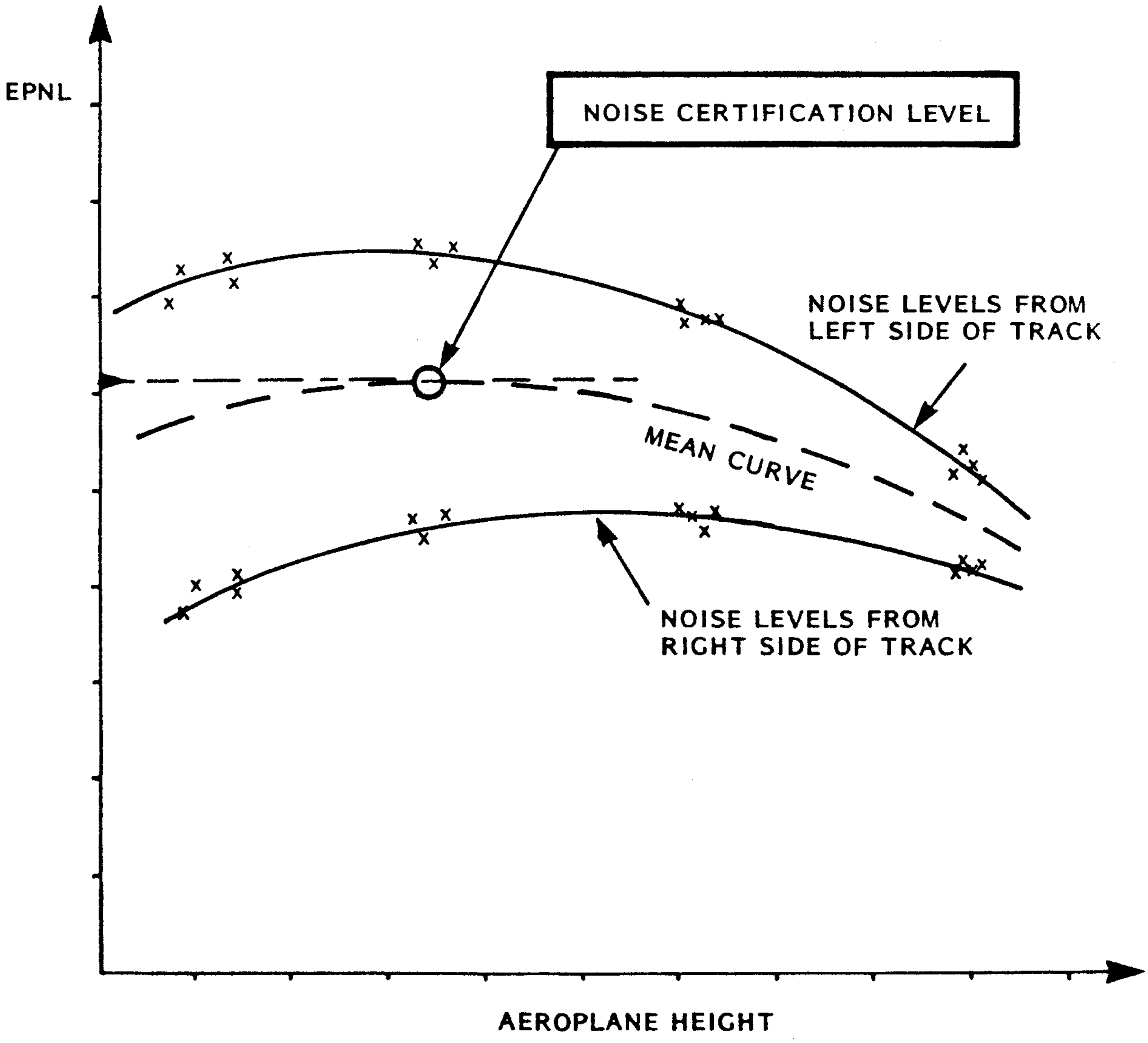


FIGURE 9

Typical lateral noise data plot for a propeller driven heavy aeroplane

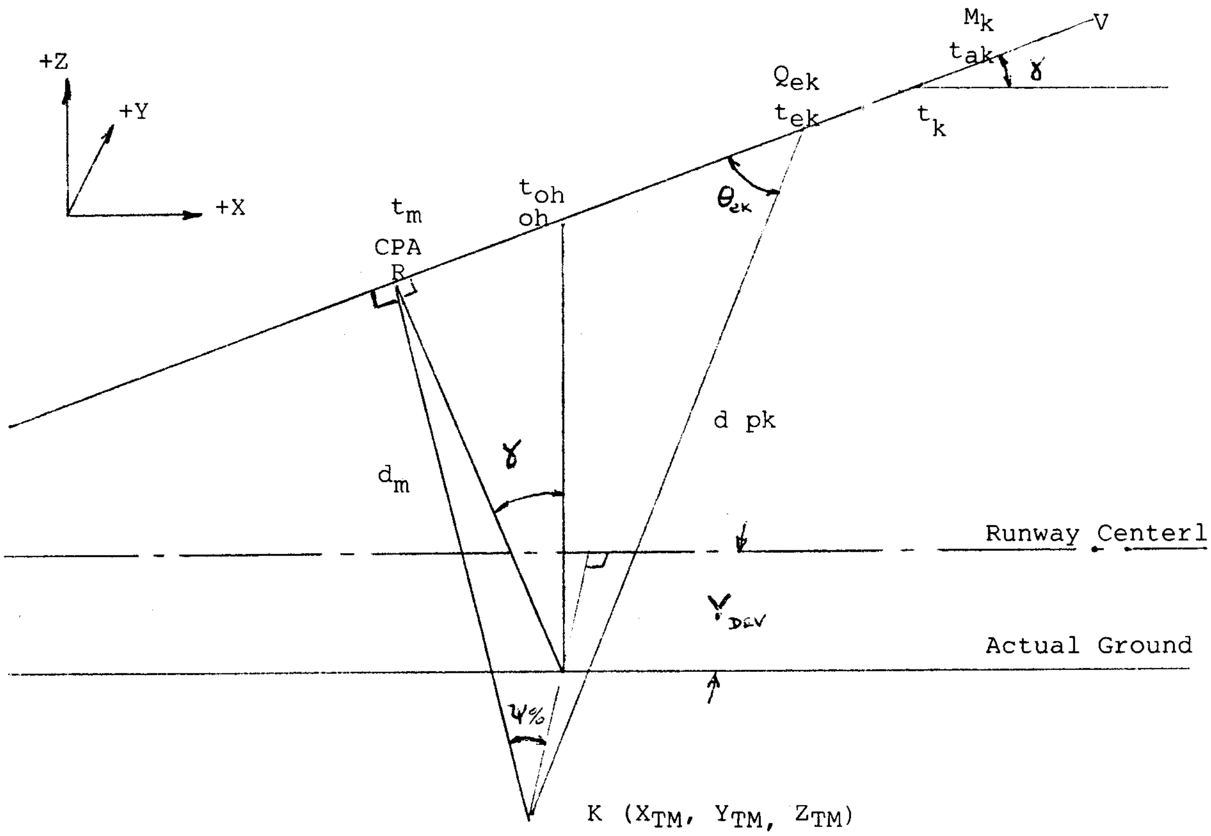


FIGURE 10 GEOMETRY FOR INTEGRATED PROCEDURE

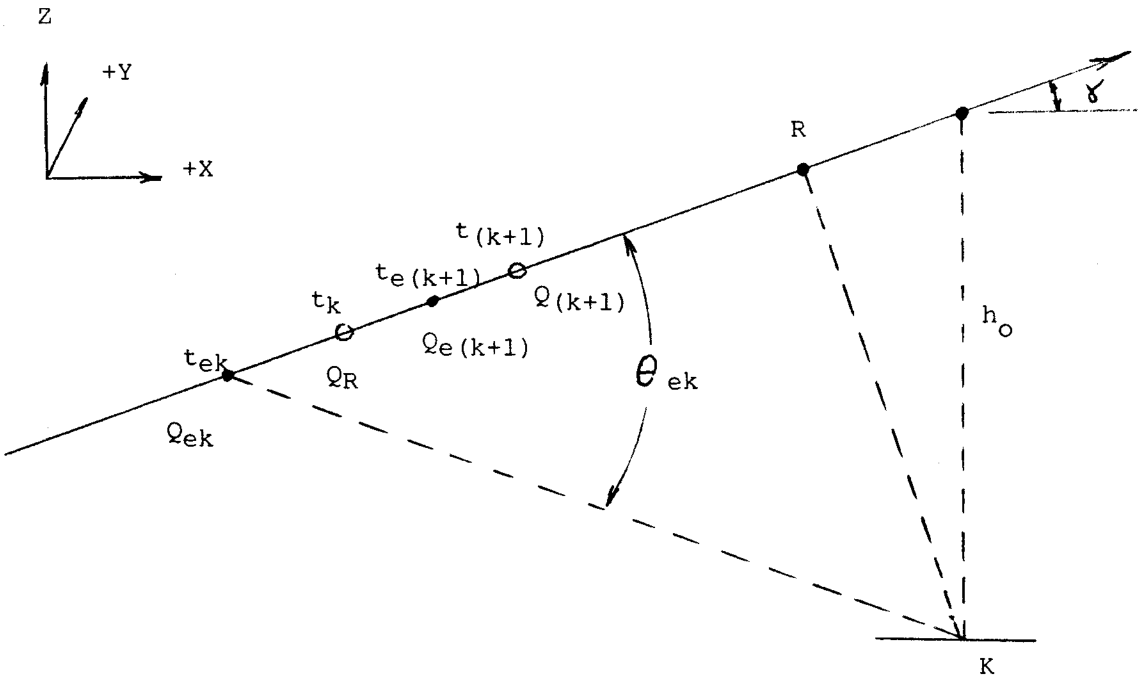


FIGURE 11 RELATIVE TIME PERIODS FOR INTEGRATED PROCEDURE

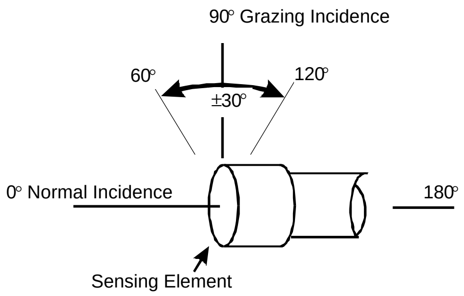


Figure 12 : Illustration of sound incidence angles on a microphone

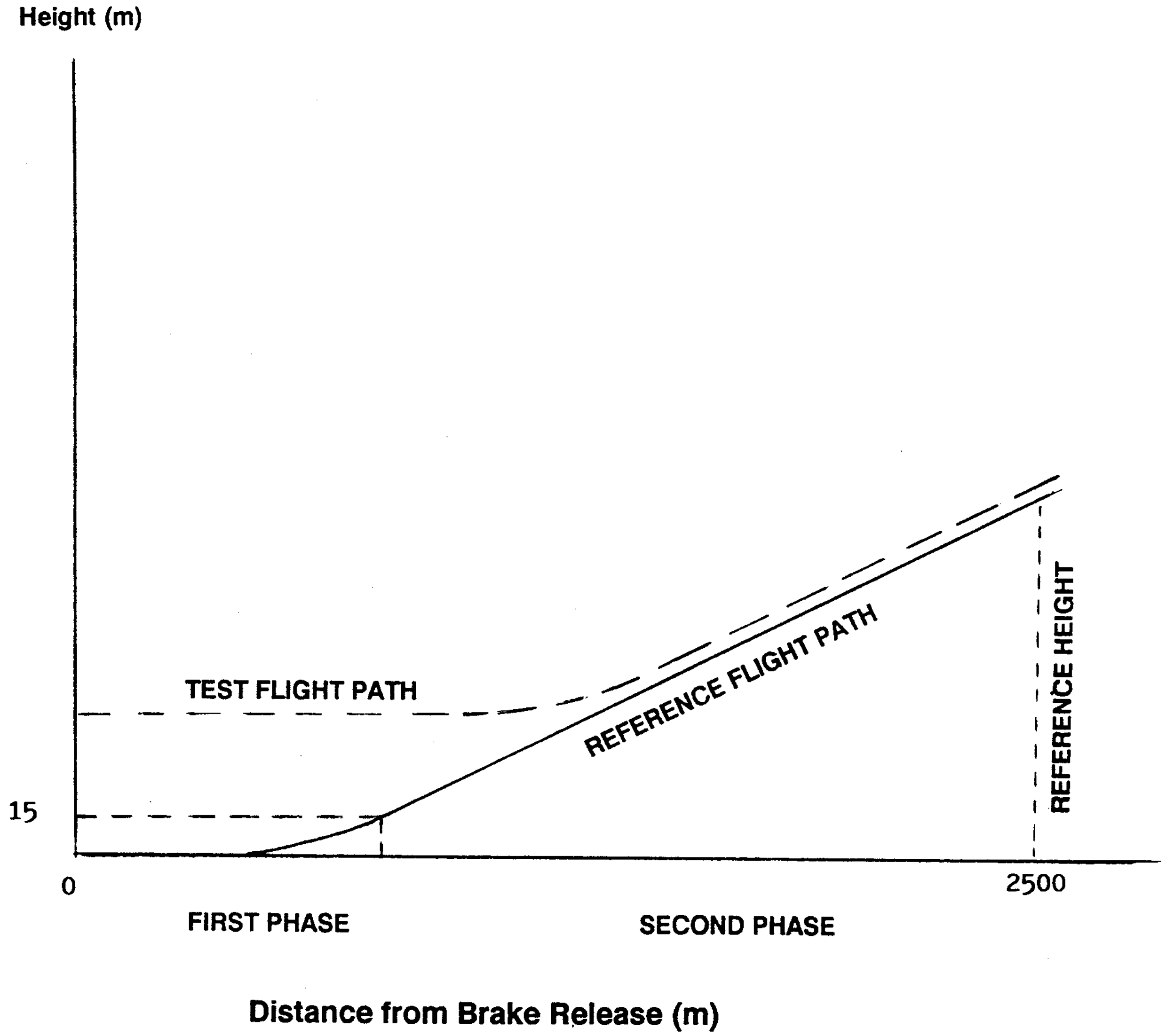


Figure 13 Typical Test and Reference Procedures

Figure 16 Radar Position Tracking System

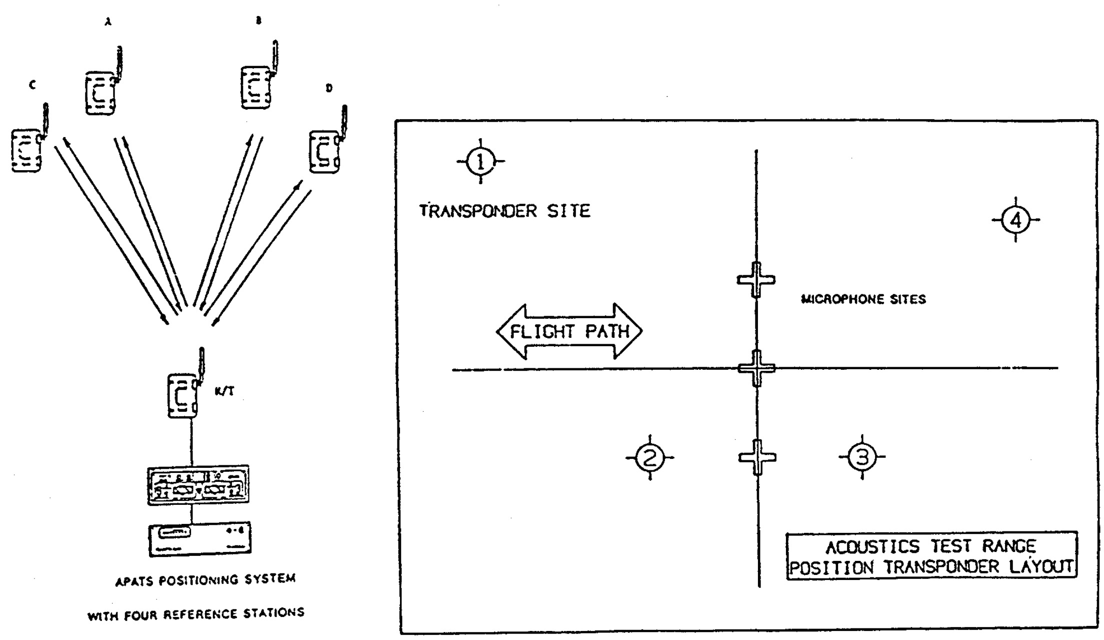
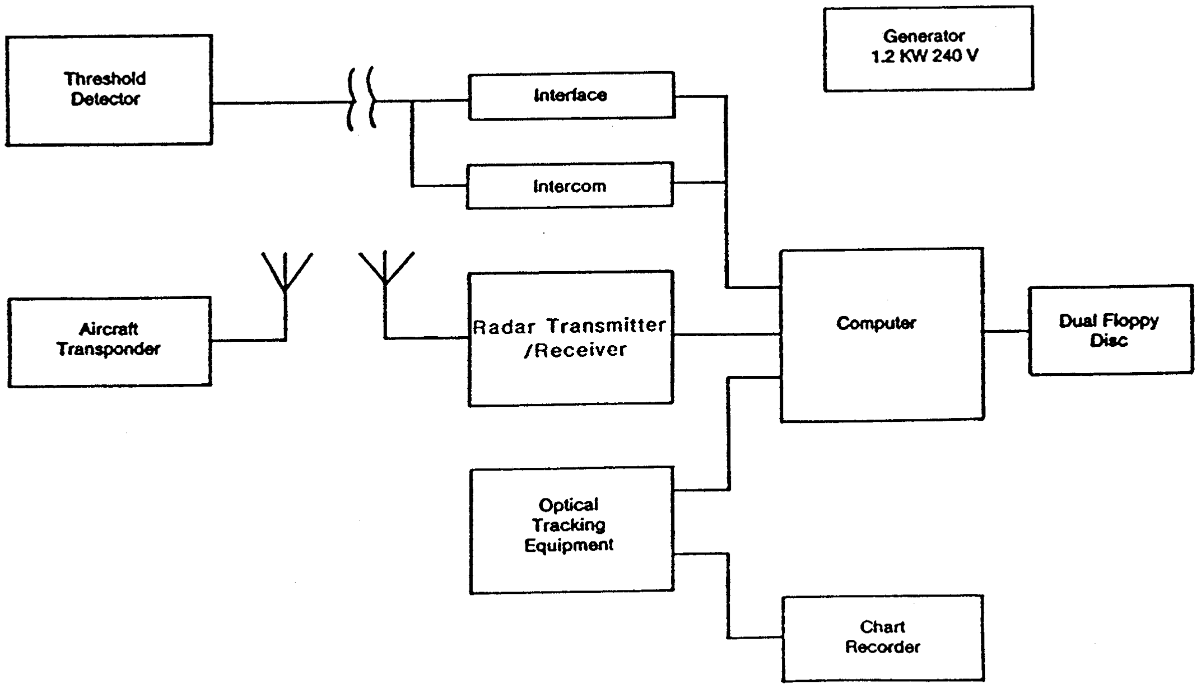
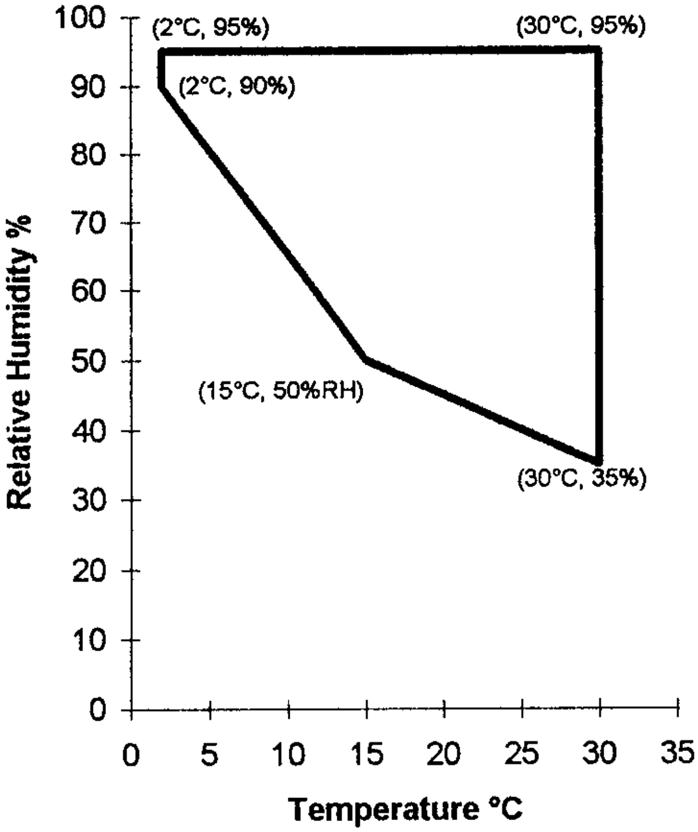


Figure 17 Radar/optical Position Tracking System





ANNEX 16, CHAPTER 8 "ZERO ATTENUATION ADJUSTMENT WINDOW"

FIGURE 16

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Appendix 1

CALCULATION OF CONFIDENCE INTERVALS

1. INTRODUCTION

The use of Noise-Power-Distance (NPD) curves requires that confidence intervals be determined using a more general formulation than is used for a cluster of data points. For this more general case confidence intervals may need to be calculated about a regression line for:

(a) flight test data,

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

(c) analytical results,

or a combination thereof.

The latter two are of particular significance for noise certifications of an aircraft model range and require special care when pooling the different sources of sampling variability.

Sections 2 to 5 provide an insight into the theory of confidence interval evaluation. The application of this theory and some worked examples are presented in Section 6. 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 $y_1, y_2, ..., y_n$ 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

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

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

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

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

2.2 **Confidence interval for mean Line obtained by regression**

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

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

and the estimate of the mean line through the data of the effective perceived noise level is given by:

$$y = b_0 + b_1 x + b_2 x^2 + \ldots\ldots + b_k x^k$$

Each regression coefficient B_i is estimated by b_i from the sample data using the method of least squares in a process summarised below.

Every observation (x_i, y_i) satisfies the equations

$$\begin{aligned} y_i &= B_0 + B_1 x_i + B_2 x_i^{\,2} + \ldots\ldots + B_k x_i^{\,k} + e_i \\ &= b_0 + b_1 x_i + b_2 x_i^{\,2} + \ldots\ldots + b_k x_i^{\,k} + e_i \end{aligned}$$

where e_i and e_i are the random error and residual associated with the effective perceived noise level. The random error, e_i , is assumed to be a random sample from a normal population with mean zero and standard deviation s . 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 s . These equations are often referred to as the normal equations.

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

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

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

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

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

Also $\underline{y = (y_1 \quad y_2 \quad . \quad . \quad . \quad y_n)}$

and $\underline{b} = (b_0 \quad b_1 \quad . \quad . \quad . \quad b_k)$

with $\underline{b}$ determined as the solution of the normal equations:

$$\underline{y} = \underline{X}\,\underline{b}$$

and $$\underline{X'}\,\underline{y} = \underline{X'}\,\underline{X}\,\underline{b} = \underline{A}\underline{b} \ ,$$

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

The 90% confidence interval, CI_{90} , for the mean value of the effective perceived noise level estimated with the associated value of the engine-related parameter, x_0 , is then defined as

$$CI_{90} = \overline{y}(x_0) \pm t_{.95,z}\ s\ v(x_0) \ \text{, where } v(x_0) = \sqrt{\underline{x}_0\,\underline{A}^{-1}\,\underline{x}'_0} \ .$$

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

where $$\underline{x}_0 = \left(1 \quad x_0 \quad x_0^{\ 2} \quad . \quad . \quad x_0^{\ k}\right),$$

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

$\overline{y}(x_0)$ is the estimate of the mean value of the effective perceived noise level at the associated value of the engine related parameter,

$t_{.95,z}$ is obtained for z degrees of freedom. For the general case of a multiple regression analysis involving K independent variables (i.e. $K+1$ coefficients) z is defined as $z = n - K - 1$ (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 $z = n - k - 1$),

and $$s = \sqrt{\frac{\sum_{i=1}^{i=n}\left(y_i - \overline{y}(x_i)\right)^2}{n - K - 1}}$$, the estimate of s, the true standard deviation.

3. CONFIDENCE INTERVAL FOR STATIC TEST DERIVED NPD CURVES

When static test data is 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, *BF* denotes baseline flight, *BS* denotes baseline static, and *DS* denotes derivative static.

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 effective perceived noise level at engine-related parameter x_0, i.e., for $m_{DF}(x_0)$, is given by:-

$$CI_{90}(x_0) = \overline{y}_{DF}(x_0) \pm t' v_{DF}(x_0)$$

where $v_{DF}(x_0) = \sqrt{\left(s_{BF}v_{BF}(x_0)\right)^2 + \left(s_{BS}v_{BS}(x_0)\right)^2 + \left(s_{DS}v_{DS}(x_0)\right)^2}$

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

$$t' = \frac{\left(s_{BF}v_{BF}(x_0)\right)^2 t_{BF} + \left(s_{BS}v_{BS}(x_0)\right)^2 t_{BS} + \left(s_{DS}v_{DS}(x_0)\right)^2 t_{DS}}{\left(s_{BF}v_{BF}(x_0)\right)^2 + \left(s_{BS}v_{BS}(x_0)\right)^2 + \left(s_{DS}v_{DS}(x_0)\right)^2}$$

where t_{BF}, t_{BS} and t_{DS} are the $t_{.95,z}$ values each evaluated with the respective degrees of freedom z_{BF}, z_{BS} and z_{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 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 above. If $\hat{\Delta}$ represents the analytically determined change and if it is assumed that it may deviate from the true unknown Δ by some random amount d, i.e.

$$\hat{\Delta} = \Delta + d \quad ,$$

where d is assumed to be normally distributed with mean zero and known variance t^2,

then the confidence interval for $m(x_0) + \Delta$ is given by

$$\left(\overline{y}(x_0) + \hat{\Delta}\right) \pm t'v'(x_0)$$

where $v'(x_0) = \sqrt{v(x_0)^2 + t^2}$ 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

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

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% CONFIDENCE INTERVALS FROM THE POOLING OF THREE DATA SETS

This section presents an example of the derivation of the 90% 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 (ie. straight line) and second order (ie. quadratic) regression curves. In addition it is shown how the confidence interval shall be established for the pooling together of several data sets.

Consider the theoretical evaluation of the certification noise levels for an aircraft retro-fitted with silenced engines. The approach noise level for the 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 data bases is assumed to be made up of data unique to each base.

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.

The two curves which determine the acoustic changes are the regression curves (in the example given both a quadratic and straight line least squares curve fit) for the plots of EPNL against normalised thrust for the hardwall and silenced conditions. These are presented in figure below. The dotted lines plotted about each line represent the boundaries of 90% confidence.

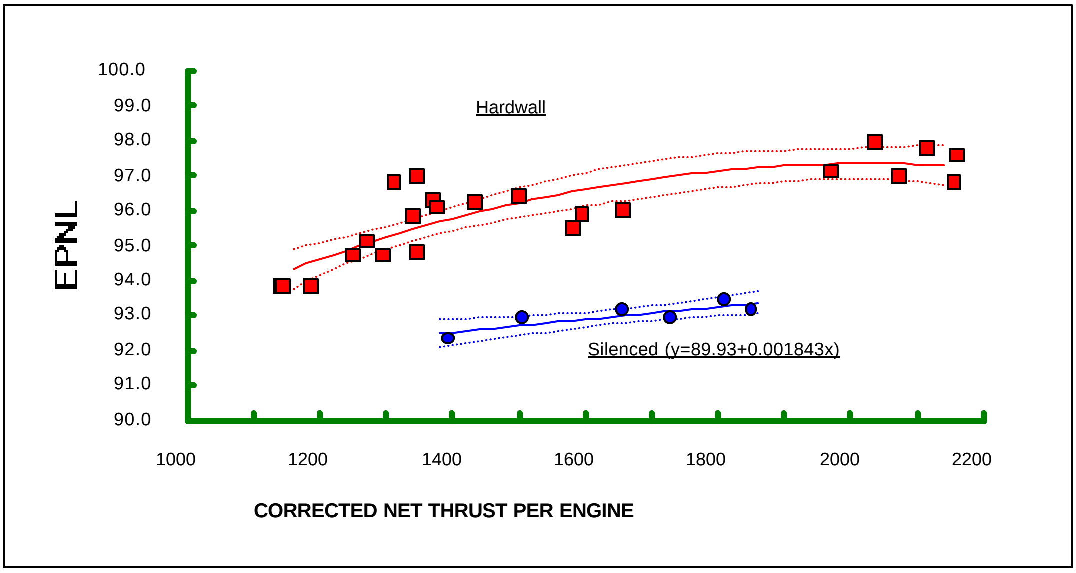

Figure 1.1

Each of the two curves is made up of 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.

6.1 Confidence interval for a clustered data set

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

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

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

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 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 1-2),

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

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

and Confidence Interval

$$CI = \overline{EPNL} \pm t \frac{s}{\sqrt{n}} = 95.38 \pm \ 2.015 \frac{0.3869}{\sqrt{6}} = 95.38 \pm \underline{\underline{0.3183}}$$

6.2 **Confidence interval for a first order regression curve**

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 ie. a first order polynomial.

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 normalised thrust F_N/d ,(in this case).

Although for higher order polynomial least squares curves a regression line's coefficients (ie. 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 formulae 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 $$S_x{}^2 = \frac{\sum_{i=1}^{i=n} X_i{}^2}{n} - \left(\frac{\sum_{i=1}^{i=n} X_i}{n} \right)^2 ,$$

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

The 90% confidence interval about this regression line for $X = x_0$ is then defined by:

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

where t = Student's t-distribution for 90% 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),

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

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

with $\underline{X}$ and $\underline{X}'$ defined as in paragraph 2.2 from the elemental vectors formed from the measured values of 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 above.

Let us suppose that our data set consists of the following set of six EPNL values 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 their number has been restricted):

Run Number	F_N/d	EPNL
1	1395	92.3
2	1505	92.9
3	1655	93.2
4	1730	92.9
5	1810	93.4
6	1850	93.2

Table 1-1

By plotting this data (See Figure 1.1) it can be seen by examination that a linear relationship between EPNL (the dependent variable Y) and F_N/d (the independent variable X) is suggested with the following general form:

$$Y = a + bX$$

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

X	Y	XY	X^2
1395	92.3	128759	1946025
1505	92.9	139815	2265025
1655	93.2	154246	2739025
1730	92.9	160717	2992900
1810	93.4	169054	3276100
1850	93.2	172420	3422500
$\sum X$	$\sum Y$	$\sum XY$	$\sum X^2$
9945	557.9	925010	16641575

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

$$S_{xy}{}^2 = \frac{\sum_{i=1}^{i=n} X_i Y_i}{n} - \frac{\sum_{i=1}^{i=n} X_i \sum_{i=1}^{i=n} Y_i}{n^2} = \frac{925010}{6} - \frac{(9945)(557.9)}{36} = 48.46$$

and $$S_x{}^2 = \frac{\sum_{i=1}^{i=n} X_i{}^2}{n} - \left(\frac{\sum_{i=1}^{i=n} X_i}{n}\right)^2 = \frac{16641575}{6} - \left(\frac{9945}{6}\right)^2 = 26289.6$$

to give $$b = \frac{48.46}{26289.6} = \underline{\underline{0.001843}}$$

and $$a = \frac{\sum_{i-1}^{i=n} Y_i - b\sum_{i=1}^{i=n} X_i}{n} = \frac{557.9 - (0.001843)(9945)}{6} = \underline{\underline{89.93}}$$

The 90% 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.

From the single set of measured independent variables tabulated in Table 1-1 let us form the matrix, $\underline{X}$, from the elemental row vectors such that:

$$\underline{X} = \begin{pmatrix} 1 & 1395 \\ 1 & 1505 \\ 1 & 1655 \\ 1 & 1730 \\ 1 & 1810 \\ 1 & 1850 \end{pmatrix},$$

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

$$\underline{X}' = \begin{pmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 1395 & 1505 & 1655 & 1730 & 1810 & 1850 \end{pmatrix}.$$

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

$$\underline{A} = \begin{pmatrix} 6 & 9945 \\ 9945 & 16641575 \end{pmatrix}$$ and its inverse $\underline{A}^{-1}$ such that

$$\underline{A}^{-1} = \begin{pmatrix} 17.5836 & -0.01051 \\ -0.01051 & 6.3396\text{E}-6 \end{pmatrix}.$$

NB. The manipulation of matrices, their multiplication and inversion, are best performed by computers via standard routines. Such routines are possible using standard functions contained within many commonly used spreadsheets.

Suppose for example we now wish to find the 90% confidence interval about the regression line for a value of F_N/d (i.e. x_0) of 1600. We form the row vector $\underline{x_0}$ such that:

$$\underline{x_0} = \begin{pmatrix} 1 & 1600 \end{pmatrix}$$ and its transpose , a column vector $\underline{x_0}' = \begin{pmatrix} 1 \\ 1600 \end{pmatrix}$.

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

$$\underline{x_0}\,\underline{A}^{-1} = \begin{pmatrix} 1 & 1600 \end{pmatrix} \begin{pmatrix} 17.5836 & -0.01051 \\ -0.01051 & 6.3396\text{E}-6 \end{pmatrix}$$

$$= \begin{pmatrix} 0.7709 & -3.6453\text{E}-4 \end{pmatrix}$$

and so $\underline{x_0}\,\underline{A}^{-1}\,\underline{x_0}' = \begin{pmatrix}0.7709 & -3.6453\text{E}-4\end{pmatrix}\begin{pmatrix}1\\1600\end{pmatrix}$

$$= 0.1876\ .$$

Our equation for confidence interval also requires that we evaluate the value of standard deviation for the measured data set. From Table 1-1 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 6 measured values of F_N/d) we proceed as follows:

Run Number	F_N/d	EPNL (Measured)	EPNL (Predicted)	$(\Delta\, EPNL)^2$
1	1395	92.3	92.50	0.03979
2	1505	92.9	92.70	0.03911
3	1655	93.2	92.98	0.04896
4	1730	92.9	93.12	0.04708
5	1810	93.4	93.26	0.01838
6	1850	93.2	93.34	0.01909

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

and so taking the value of Student's t from Table 1-2 for $(n-k-1)$ degrees of freedom (i.e. 4) to be 2.132, we have the confidence interval about the regression line at $F_N/d = 1600$ defined as follows:

$$CI_{90} = \overline{\text{EPNL}} \pm \text{t}\, s\sqrt{\underline{x_0}\,\underline{A}^{-1}\,\underline{x_0}'} = 92.98 \pm (2.132)(0.2304)\sqrt{0.1876} = 92.98 \pm \underline{\underline{0.2128}}$$

In order to establish the lines of 90% 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 1.1

6.3 **Confidence interval for a second order regression curve**

The confidence intervals about a second order regression curve are derived in a similar manner to those for a straight line detailed in Section 6.1. It is not felt that a detailed example of their calculation would be appropriate. However the following points should be borne in mind.

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.

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:

$$CI_{90} = \overline{Y} \pm t\, s\sqrt{\underline{x_0}\,\underline{A}^{-1}\,\underline{x_0}'}$$

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:

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

The number of degrees of freedom associated with a multiple regression analysis involving K variables independent of the dependent variable (ie. 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 $(n-3)$.

6.4 **Confidence interval for the pooled data set**

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

$$CI = \overline{Y} \pm T'\sqrt{\sum_{i=1}^{i=3} Z_i^2}$$

where $Z_i = \frac{CI_i}{t_i}$, with CI_i = confidence interval for the i'th data set and t_i = value of Student's t for the i'th data set,

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

The different stages in the calculation of the confidence interval at our reference thrust of $F_N/d = 1600$ for the pooling of our three data sets is summarised below:

Description	Function	Datum	Hardwall	Silenced
Reference Thrust	F_N/d		1600	1600
90% 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	t	2.015	1.725	2.132
Z	CI_{90}/t	0.1580	0.2792	0.09981
Z^2	$\left(CI_{90}/t\right)^2$	2.4953E-2	7.7979E-2	9.9625E-3
Z^2t	$\left(CI_{90}/t\right)^2 t$	5.0280E-2	0.1345	2.1240E-2
$\sum Z^2$		0.1129		
$\sum\left(Z^2t\right)$		0.2060		
T	$\sum\left(Z^2t\right) / \sum Z^2$	1.8248		
$\sqrt{\sum Z^2}$		0.3360		
CI	$T\sqrt{\sum Z^2}$	0.6131		

7. **BIBLIOGRAPHY**

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

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

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

4. Cochran, W.G., Approximate Significance Levels of the Behrens-Fisher Test, Biometrics, 10 191-195, 1964.

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

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

7. Wonnacott, T.H. and Wonnacott, R.J., Introductory Statistics, 5th ed., John Wiley & Sons, 1990

Degrees of Freedom (ζ)	$t_{.95,z}$
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

Values in the Student's t-distribution to give a probability of 0.95 that the population mean value, m , is such that:

$m \leq \overline{y} + t_{.95,z} \frac{s}{\sqrt{n}}$, and thus a probability of 90% that

$$\overline{y} - t_{.95,z} \frac{s}{\sqrt{n}} \leq m \leq \overline{y} + t_{.95,z} \frac{s}{\sqrt{n}} \ .$$

Student's t-DISTRIBUTION (FOR 90% CONFIDENCE INTERVAL)
FOR VARIOUS DEGREES OF FREEDOM

TABLE 1-2

Appendix 2

IDENTIFICATION OF SPECTRAL IRREGULARITIES

1.0 INTRODUCTION

Spectral irregularities which are not produced by aircraft noise sources may cause tone corrections to be generated when the procedures of Annex 16, Volume 1 paragraph 4.3 of Appendix 1 and 2, 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 1/3 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 1 tone correction procedures is used;

b) small perturbations in the propagation of aircraft noise when analysed with 1/3 octave bandwidth filters; or

c) the data processing adjustments and corrections such as the background noise correction method and the adjustment for atmospheric attenuation. In the case of the latter, the atmospheric attenuation coefficients (α) given in ARP866A ascribe α values at 4 kHz to the centre frequency of the 1/3 octave band whereas at 5 kHz the value of α is ascribed to the lower pass frequency of the 1/3 octave. This difference is sufficient in some cases to generate a tone correction.

The inclusion of a tone correction factor in the computation of 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 above causes may be disregarded. This Appendix describes methods which have been approved for detecting and removing the effects of such spectral irregularities. However, approval of the use of any of these methods remains with the certificating authority.

2.0 METHODS FOR IDENTIFYING FALSE TONES

2.1 Frequency tracking

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:-

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

where f is the frequency of the noise at source
M is the Mach number of the aeroplane
l 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.

Reflection related effects in the spectra, i.e. pseudotones, decrease in frequency prior to, and increase in frequency after, passing the closest point of aeroplane passing overhead, or the lateral point. 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 1/3 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 paragraph 2.1.

2.3 Microphone mounting height

Comparison of 1/3 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 paragraph 4.4 of Appendix 6 of ICAO Annex 16, volume 1, 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 (b) above) 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 to 0.6 dB. Time histories of perceived noise levels, PNL, 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 to demonstrate that such tone corrections are not due to aeroplane generated noise.

3.0 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 in Step 9 of the tone correction calculation (described in Section 4.3 of Appendix 2 of Annex 16, Volume 1) may be set to zero.

Appendix 3

A PROCEDURE FOR REMOVING THE EFFECTS OF AMBIENT NOISE LEVELS FROM AEROPLANE NOISE DATA

1.0 INTRODUCTION

1.1 The following information is provided as guidance material for certificating authorities on the method of removing the effect of ambient noise on aeroplane recorded noise.

1.2 This is not the only procedure which may be used and changes under certain instances may be made to it, but approval for its use in its current or modified form remains with the certificating authority.

2.0 Correction procedure

2.1 Aeroplane sound pressure levels within the 10 dB down points should exceed the mean ambient noise levels determined in section 7.5.6 of the manual by at least 3 dB in each one-third octave band or be corrected by the following or similar method.

1) The identification of the pre-detection and post-detection noise are made, i.e.:

a) one which adds to the recorded noise data on an energy basis, such as that from extraneous acoustic background noise signals or electrical noise from the microphone pre- amplifier and tape recorder is termed pre-detection noise; and

b) one which is non-additive but masks the aeroplane noise signal, such as would be produced by the presence of a lower level 'window' of the signal analyser, is termed post-detection noise.

2) Over the frequency range of the pre-detection noise, the background noise is subtracted from the analysed noise on an energy basis.

a) at frequencies of 630 Hz and below, if the analysed level is within 3 dB of the background pre-detection noise level ('masked' band), the corrected aeroplane noise is set equal to the pre-detection background level. If the analysed level is less than the background level, no changes are made to this level; and

b) at frequencies above 630 Hz, if the analysed level is within 3 dB or less than the pre-detection noise level, these levels are also identified as 'masked' and are corrected as in Steps 4), 5) and 6).

3) The remaining bands which fall inside the frequency range of the post-detection background noise are uncorrected unless they are within 3 dB of the identified post-detection noise, these bands are thus identified as 'masked' bands.

4) The 'as measured' spectrum is normalised to reference day conditions (25 C, 70% RH) and a distance from source of 60 m.

5) For the 'masked' high frequency bands at 60 m a linear extrapolation from the next lower frequency unmasked band of 0 dB/one-third octave, or a greater slope if derived from measured data, is applied.

6) The normalised spectrum is then converted back to 'as measured' distances and atmospheric conditions.

Note: If 'masked' pre- or post-detection bands are surrounded on both sides by 'unmasked' bands, no corrections are applied.

2.2 The following procedure is applicable to measured data where more than seven consecutive one-third octave bands are masked during a period of the noise time history.

Corrections by extrapolating in the time domain for frequencies above 630 Hz are made by taking into account propagation distance (spherical divergence and atmospheric attenuation) relative to the first (approaching) or last (receding) unmasked sound pressure level measurement in the one-third octave band requiring correction.

Source directional characteristics in each masked frequency band are assumed to be either:

a) directional, as supported by the applicant's test data or in the absence of such data; or

b) omnidirectional.

Appendix 4

REFERENCE TABLES AND FIGURES 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 4-1. 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	3.99	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	16.4	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	9.05	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	29.9	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	46.5	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	243	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	1488	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	2040									
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 4-2 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	|ΔS| dB Step 2	SPL' dB Step 4	S' dB Step 5	$\bar{S}$ 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	2 1/3	0.29
7	200	82	+2	8	82	+ 2	−1⅓	80⅓	1 2/3	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 instructions
Step 4	see instructions
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 2-1 *

Note.— Steps 5 and 6 may be eliminated in the calculations if desired. In this case in the example shown in Table 4-2 *columns 7 and 8 should be removed and existing 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 2-1*

* Table 2-1 of Appendix 2 of Annex 16 Volume 1

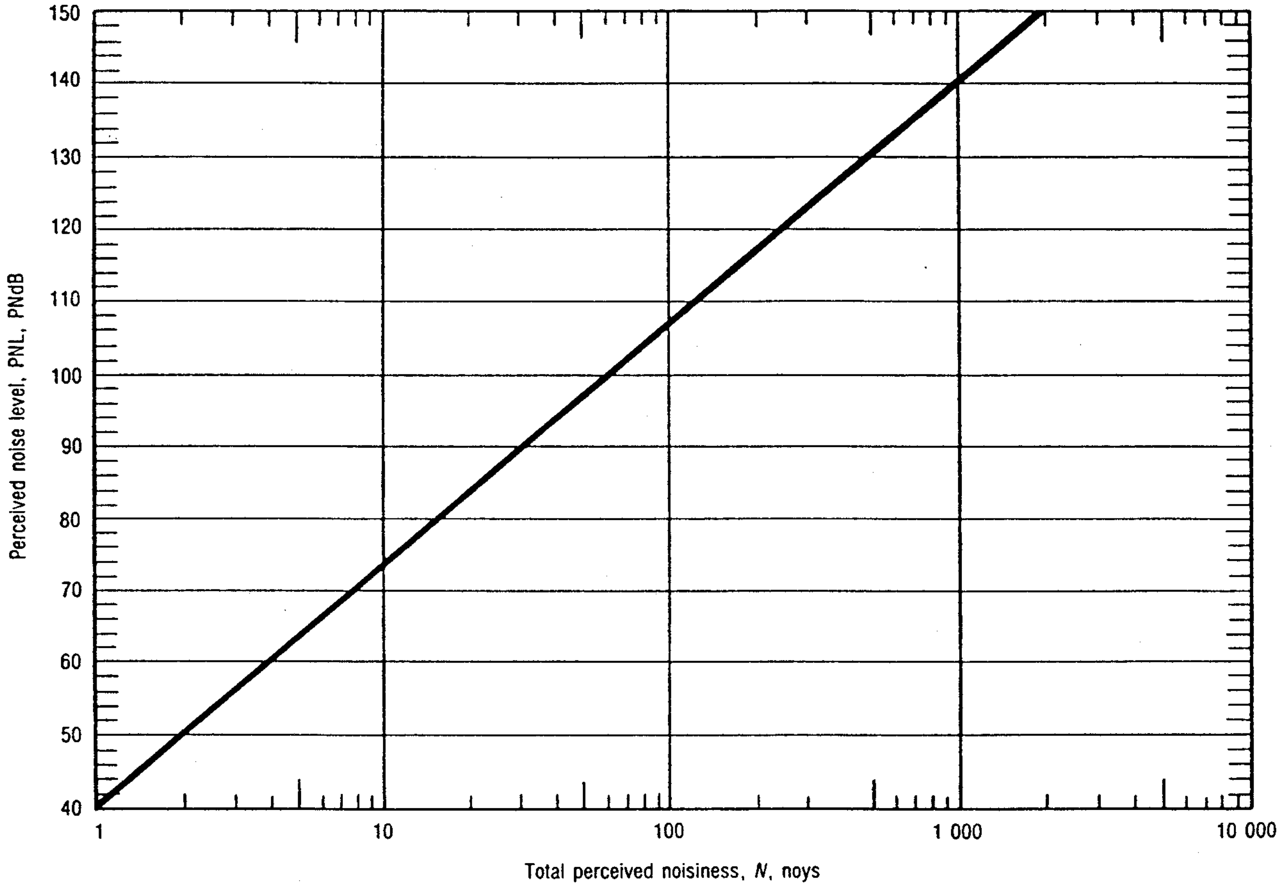

Figure 4-1. Perceived noise level as a function of total perceived noisiness

<u>Appendix 5</u>

WORKED EXAMPLE OF CALCULATION OF REFERENCE FLYOVER HEIGHT AND REFERENCE CONDITIONS FOR SOURCE NOISE ADJUSTMENTS FOR CERTIFICATION OF LIGHT PROPELLER DRIVEN AEROPLANES TO ICAO ANNEX 16, VOLUME 1, CHAPTER 10

1. INTRODUCTION

The reference flyover height for an aeroplane certificated to Chapter 10 of Annex 16 is defined for a point 2500 m from start of roll beneath a reference flight path determined according to the take-off reference procedure described in Paragraph 10.5.2 of the Annex. 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

The take-of reference procedure for an aeroplane certificated to Chapter 10 is defined under sea level, ISA conditions, at maximum take-off mass for which noise certification is requested, in Paragraph 10.5.2 of the Annex. The procedure is described in terms of two phases.

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

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.

Note 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

The reference flyover height is defined according to the take-off reference flight path at a point 2500 m from start of roll for an aeroplane taking-off from a paved, level runway under the following conditions:

– sea level atmospheric pressure of 1013.25 hPa;
– ambient air temperature of 15°C, i.e. ISA
– relative humidity of 70 per cent; and
– zero wind.

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

$$H_R = \left(2500 - D_{15}\right)\tan\left(\sin^{-1}\left(RC/V_y\right)\right) + 15 \qquad \text{Equation 1}$$

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/s) 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/s) corresponding to *RC*.

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 and the air speed in knots. In such instances the expression for reference flyover height, H_R ft, becomes:

$$H_R = (8203 - D_{50}) \tan\left(\sin^{-1}\left(RC/101.4V_y\right)\right) + 50 \qquad \text{Equation 2}$$

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/m); and

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

The performance figures can normally 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 using gross, i.e. unfactored, data.

In addition V_y, the best rate of climb speed, used in the expression above is defined as the true air speed (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

Paragraphs 5.2c and 5.2d of Appendix 6 of the Annex 16, Volume 1 describe how corrections for differences in source noise between test and reference conditions shall be made.

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.

The reference temperature at this height 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 1000 ft. The reference temperature, T_R °C, can be defined as:

$$T_R = 15 - 1.98(H_R/1000) \qquad \text{Equation 3}$$

The reference atmospheric pressure, P_R hPa, is similarly calculated at the reference height for a standard sea level pressure of 1013.25 hPa assuming a standard pressure lapse rate:

$$P_R = 1013.25\left[1 - \left(6.7862\text{x}10^{-6} H_R\right)\right]^{5.325} \qquad \text{Equation 4}$$

5. WORKED EXAMPLE

A worked example is presented for the calculation of reference flyover height and the associated reference atmospheric conditions.

4.1 Example of reference flyover height calculation

In Figure 5-1 extracts are presented from the performance section of a flight manual for a typical light , single engined propeller driven aeroplane.

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

The take-off distance to 50 ft at the reference conditions of Chapter 10 can be read from the table of take-off distances presented for a paved runway at the maximum certificated take-off weight of 1920 lb. Thus D_{50} is 1370 ft.

The rate of climb at the reference conditions can similarly be read from the rate of climb table. Thus RC is 1000 ft/m.

The climb speed associated with the rate of climb figures is given as 80 kIAS. The corresponding true air speed at the reference conditions of Chapter 10 is equal to the indicated airspeed corrected according to the airspeed calibration table at the appropriate flap setting of 0°. Thus V_y is 81 kTAS.

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

$$H_R = (8203 - 1370)\tan\left(\sin^{-1}\left(1000/101.4 \times 81\right)\right) + 50$$

and so $\underline{H_R = 888 \text{ ft}}$.

4.2 Example of calculation of reference atmospheric conditions

The reference temperature at the reference height, H_R, is given by Equation 3:

$$T_R = 15 - 1.98(888/1000)$$

and so $\underline{T_R = 13.2\ °\text{C}}$.

The reference pressure at this height is given by Equation 4:

$$P_R = 1013.25\left[1 - \left(6.7862\text{x}10^{-6}\text{ x}888\right)\right]^{5.325}$$

and so $\underline{P_R = 981 \text{ hPa}}$.

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 pilots responsibility to apply safety factors which must not be less than those.....

6. AIRSPEED CALIBRATION

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

TAKE-OFF DISTANCE - PAVED RUNWAY (1)
CONDITIONS
Flaps - 15°....................Rotation speed - 53 KIAS
Power - Full throttle......Speed at 50 ft - 65 KIAS
Weight - 1920 lbs

AIRFIELD HEIGHT FT	ISA -20°C		ISA -10°C		**ISA**	
	Grnd Roll	Total to 50 ft	Grnd Roll	Total to 50 ft	Grnd Roll	**Total to 50 ft**
Sea Level	530	1230	565	1290	600	**1370**
5000	1045	2835	1065	2435	1090	2580
10000	1465	3335	1490	3390	1510	3435
AIRFIELD HEIGHT FT	ISA +10°C		ISA +20°C		ISA +30°C	
	Grnd Roll	Total to 50 ft	Grnd Roll	Total to 50 ft	Grnd Roll	Total to 50 ft
Sea Level	700	1580	750	1715	840	1900
5000	1170	2670	1295	2840	1290	2905
10000	1575	3560	1610	3695	1670	3790

RATE OF CLIMB
CONDITIONS
Flaps UP
Full throttle
Weight - 1920 lbs
Speed - 80 KIAS

PRESSURE ALTITUDE FT	RATE OF CLIMB FEET/MINUTE			
	ISA-20°C	ISA	ISA+10°C	ISA+20°C
Sea Level	1035	**1000**	915	825
1000	980	945	860	770
2000	925	890	805	720
3000	870	830	750	665
4000	815	775	695	610
5000	765	720	640	560
6000	700	665	585	505
7000	635	605	560	450
8000	570	550	475	395
9000	495	480	410	335
10000	415	405	335	270

Figure 5-1. Example of Flight Manual Performance Section

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. 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 /1000 ft) which is normally used for test sites not approximately at sea level, and applies to tests conducted at sites at or above 366 m (1200 ft) mean sea level (MSL).

2. JET NOISE SOURCE CORRECTION

2.1 Flight test site locations at or above 366 m (1200 ft) MSL, but not above 1219 m (4000 ft) MSL, may be approved provided the following criteria (Figure 6-1) are met and source noise corrections (paragraph 2.3) are applied. Alternative criteria or corrections require the approval of the certificating authority.

2.2 **Criteria**

Jet source noise altitude corrections from paragraph 2.3 are required for each one-half second spectrum when using the integrated procedure and at the PNLTM spectrum when using the simplified procedure (see paragraph 9.3 and 9.4 of Appendix 2 of Annex 16, Volume 1), and are to be applied in accordance with the following criteria:

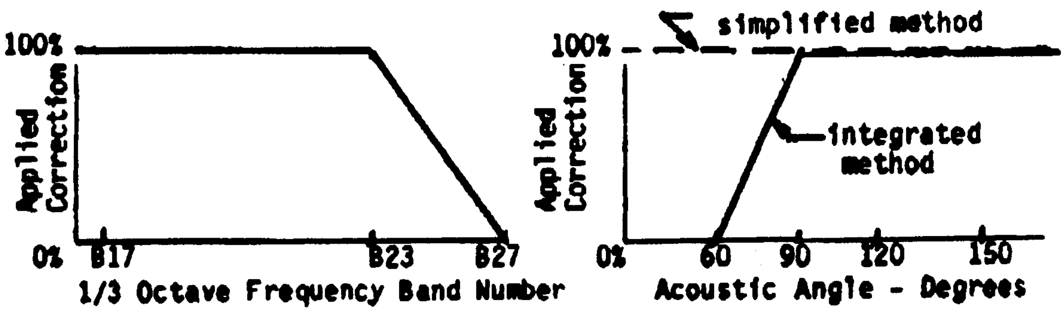

Figure 6-1

2.3 **Correction Procedure**

An acceptable jet source noise correction is as follows:

a) Correct each one-half second spectrum (or PNLTM one-half second spectrum, as appropriate) in accordance with the criteria of paragraph 2.2 using the following equation:

$$\Delta \mathrm{SPL} = \left[10\log(d_R/d_T) + 50\log(c_T/c_R) + 10k\log(u_R/u_T)\right]\,[F1]\,[F2]$$

where: Subscript T denotes conditions at the actual aeroplane test altitude above MSL under standard atmospheric conditions, i.e. ISA+10°C and 70% 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% relative humidity;

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 ARP876D, 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 $N1C_{TEST}$ 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 $N1C_{TEST}$ for standard atmosphere at the aeroplane test altitude;

N1C is the corrected engine rpm $\left(N_1 \big/ \sqrt{q_{T_2}}\right)$;

F1 is a factor corresponding to the percentage of applied correction related to acoustic angle in Figure 6-1 (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 6-1 (values range from 0.00 to 1.00).

b) For each one-third octave band SPL, arithmetically add the altitude jet noise correction in a) above to the measured SPL's to obtain the altitude source jet noise corrected SPL's for paragraph 4.1.3a of Appendix 2 of Annex 16, Volume 1.

c) The above 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).

Appendix 7

TECHNICAL BACKGROUND INFORMATION ON THE GUIDELINES FOR THE NOISE CERTIFICATION OF TILTROTOR AIRCRAFT

1. INTRODUCTION

The Guidelines for the Noise Certification of Tiltrotor Aircraft presented in Attachment YY of ICAO Annex 16, Volume 1, have been developed by the ICAO CAEP Tiltrotor Task Group specifically for the noise certification of the Bell/Agusta 609, the first example of a civil tiltrotor aircraft. Nevertheless it is intended that these guidelines be used as the basis for noise certification of subsequent tiltrotor aircraft. The following explanatory material 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 for use with other tiltrotor aircraft and their possible eventual adoption into the Annex as a Standard.

2. GENERAL TECHNICAL INFORMATION

2.1 Aeroplane mode, helicopter mode

The term “aeroplane mode” is used for the situation where 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). The term “helicopter mode” is used where the rotors are orientated with their axis of rotation substantially vertical (nacelle angle around 90 degrees). In the guideline the latter 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

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). The “gate”-concept is expected to be typical for all future tiltrotors, 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 “authorised 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 using the so-called “down stop”

2.4 Rotor RPM

The design of the Bell/Agusta 609 and most likely future designs of tiltrotors will have at least two possible Rotor RPM’s: 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 to be able to hover.

2.5 Form and extent of the guideline

It is considered that at this moment there is not enough experience with tiltrotor aircraft to justify adoption of firm standards. Therefore guidance material has been developed as “green pages” for the Annex, much like the guidelines for noise certification of Propeller driven STOL aeroplanes that are already in green pages.

It was deemed desirable to give the same level of detail as is found in comparable chapters of the Annex and for instance include information on date of applicability to promote a uniform application of the guidelines.

After careful deliberations it has been concluded that the current standards of Chapter 8 were a good basis for the guidelines and that the differences between the guideline and Chapter 8 should be minimised:

- The noise from tiltrotors will be most prominent during departure and approach. In these situations tiltrotors will normally operate in or near the “helicopter mode”.

- In the development of the guidelines the noise of the Bell XV15 tiltrotor 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 tiltrotors that can only take off vertically, excluding those having 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 tiltrotors is considered to be the same as for helicopters.

- Tiltrotors 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

One of the items of strongest interest is the transition from one nacelle angle to the other. It could be that this would be associated with particular noise generation mechanisms. For example, when one considers the tiltrotor transition from aeroplane mode to helicopter mode while decelerating there is a phase in which the component of the speed vector 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.

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 tiltrotor (XV15) passed overhead at 500 ft while transitioning from aeroplane to helicopter mode. No special phenomena were noticed during this flight. Also 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 heard from different positions relative to the aircraft. No particular noise was heard.

Based on this experience and the arguments stated below it has been decided not to attempt to define a special test point aimed at catching transition noise of tiltrotors.

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 phenomenon is virtually impossible.

- If in future there would be a design that would have clear transitional noise characteristics the effect could be studied and if deemed necessary an amendment to the guideline 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 YY)

The proposed definition was proposed by ICCAIA. It focuses on the fundamental difference between tiltrotors and other aircraft.

3.2 Applicability (re note 2 and section 1.1 of attachment YY)

As mentioned before, an applicability section has been to promote uniform application of the standards. The reference to derived versions has the effect that no measurements are required on aircraft that are quieter than their parents, due to the definition of derived versions in Annex 16. The date chosen is the date when this section of the guideline was discussed.

3.3 Noise Evaluation Measure (re section 2)

In view of the commonality with helicopters, the same units as used for Chapter 8 are proposed. It is proposed not to create a new appendix for tiltrotors, since the current appendix 2 is considered to be appropriate. For land use planning purposes it is proposed to have additional data 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. At this moment, the intention of this section of the guideline is to only require data that can be gathered through additional analysis of the data already measured for certification purposes. It is hoped to have SAE 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 it available to the public.

3.4 Noise Measurement Reference Points (re section 3)

In view of the desired commonality with helicopters, the same Noise measurement reference points as used for Chapter 8 are proposed.

3.5 Maximum Noise Levels and trade-offs. (re section 4 and 5)

For the reasons already mentioned under “form” it is considered that the current Chapter 8 limits and trade-offs to be a good starting point for use in the guideline. In helicopter mode both the lift technology and operating environment are similar to that of a helicopter. If technology requires higher levels or makes possible lower levels 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 most likely configuration to be used when flying the circuit pattern.

3.6 Noise Certification reference procedures (re section 6)

The capability to change the nacelle angle and the two different, possibly more RPMs require some additions to the current Chapter 8 helicopter reference procedures.

3.7 RPM

In the guideline 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

In **take-off** the choice of the nacelle angle is left to the applicant. This is in line with the philosophy elsewhere in the Annex, where the choice of the configuration is left to the applicant. It is also in line with the requirement in Chapter 8 to use 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”.)

For the case of **Fly-over 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 tiltrotor 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 by selecting a nacelle angle of approximately 80 degrees. It was agreed that this unique capability of the tiltrotor 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 to close to zero 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 tiltrotor 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.

In the **fly-over 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. One is with the high RPM and the same speed as used in the helicopter mode flyover. This condition is intended to give the possibility to make comparisons between the helicopter mode and aeroplane mode flyover. The other condition is with the cruise RPM and speed Vmcp or Vmo, which is intended to represent a worst case cruise condition.

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 the Annex that require the noisiest configuration for approach. This will normally require testing several different nacelle angles in order to determine which is noisiest.

In the tiltrotor aircraft design the flap angle varies with airspeed the pilot may manually set flaps or may use autoflap control in order to reduce the pilot 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)

The test procedures are the same as in Chapter 8. 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 to maintain commonality with Chapter 8 numbers and to reduce costs for the applicant. If for Land Use Planning or other purposes it were desired to have data at other microphone positions (i.e. at ground plane) this would of course be allowed but would have to be agreed between applicant and certificating authority.

Appendix 8

REASSESSMENT CRITERIA FOR THE RE-CERTIFICATION OF AN AEROPLANE FROM ICAO ANNEX 16, VOLUME 1, CHAPTER 3 TO A MORE STRINGENT STANDARD

1. INTRODUCTION

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".

This Appendix is restricted to the assessment of existing approved noise levels associated with applications for the re-certification of an aeroplane from ICAO Annex 16, Volume 1, Chapter 3 to a more stringent standard. It may be developed in the future to include guidelines for the re-certification of aircraft specially modified for the purpose of achieving compliance with a new standard and the re-certification of helicopters and light propeller driven aeroplanes to a different standard from that to which they were originally certificated.

In the case of an aircraft being re-certificated from the standards of ICAO Annex 16, Volume 1, Chapter 3 to a more stringent standard that may be directly applicable to new type designs only, 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.

2. REASSESSMENT CRITERIA

Noise levels already approved to Chapter 3 and submitted in support of applications for re-certification of existing aircraft should be assessed against the criteria presented below. 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 data was obtained and subsequently processed. The questions are the result of a comparison of the various amendments and revisions to the Annex and Environmental Technical Manual to which an aircraft's existing Chapter 3 noise levels may have been approved.

2.1 For aeroplanes which were approved in accordance with Amendment 5, or higher, of ICAO Annex 16, Volume 1, a reassessment is not required. The aeroplane's existing, approved Chapter 3 noise levels shall be used to determine compliance with the new standard.

2.2 For aeroplanes which were approved in accordance with Amendment 4, or lower, of ICAO Annex 16, Volume 1, the applicant shall be required to show that the existing approved Chapter 3 noise levels are equivalent to those approved to Amendment 5 by answering the following questions (paragraph references refer to either Amendment 5 of ICAO Annex 16, Volume 1 or WGAR/6 of this Manual:

For <u>all</u> aeroplanes:

a) **Was full take-off power used throughout the reference flight path in the determination of the lateral noise level?** (Annex 16, paragraph 3.6.2.1c refers);
b) **Was the "average engine" rather than the "minimum engine" thrust or power used in the calculation of the take-off reference flight path?** (Annex 16, paragraphs 3.6.2.1a and 3.6.2.1g refer);
c) **Was the "simplified" method of adjustment defined in Appendix 2 of the Annex used and, if so, was -7.5 used as the factor for the calculation of the noise propagation path duration correction term?** (Annex 16, Appendix 2, paragraph 9.3.3.2 refers)
d) **Was the take-off reference speed between V_2+10 kt and V_2+20 kt?** (Annex 16, paragraph 3.6.2.1d refers); and
e) **Was the four ½ s linear average approximation to exponential averaging used and, if so, were the 100% weighting factors used?** (Annex 16, Appendix 2, paragraph 3.4.5, Note 1 refers).

For <u>jet</u> aeroplanes only:

f) **Were the noise measurements conducted at a test site below 366 m (1200 ft) and, if not, was a jet source noise correction applied?** (Technical Manual, Appendix 6 refers);

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?** (Technical Manual, paragraph 2.1.3.2b refers);

h) **In the event that "family" certification methods were used were the 90% confidence intervals for the pooling together of flight and static engine test data established according to the Technical Manual guidance?** (Technical Manual, Appendix 1 refers); and

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)?** (Technical Manual, paragraph 2.3.3.4.1 refers).

For <u>propeller driven</u> aeroplanes only:

j) **Were symmetrical microphones used at every position along the lateral array for the determination of the peak lateral noise level?**(Annex 16, paragraph 3.3.2.2);

k) **Was the approach noise level demonstrated at the noisiest configuration?** (Annex 16, paragraph 3.6.3.1e refers); and

l) **Was the target airspeed flown during the flight tests appropriate to the actual test mass of the aeroplane?** (Technical Manual, paragraph 3.1.2a).

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 aeroplane's existing, approved Chapter 3 noise levels shall be used to determine compliance with the new standard. Otherwise the certificating authority may require such re-analysis or re-testing that may be necessary in order to bring the data up to the required standard.