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Environmental Technical Manual

Volume I
Procedures for the Noise Certification of Aircraft

CAEP10 Steering Group 2015 approved revision
(Based on Second Edition — 2015)

International Civil Aviation Organization

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AMENDMENTS

Amendments are announced in the supplements to the *Publications Catalogue;* the Catalogue and its supplements are available on the ICAO website at www.icao.int. The space below is provided to keep a record of such amendments.

RECORD OF AMENDMENTS AND CORRIGENDA

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FOREWORD

This revision of Doc 9501, Volume I, First Edition, includes material that has been approved by the ICAO Committee on Aviation Environmental Protection (CAEP) Steering Group at its third meeting of the CAEP/10 cycle in July 2015. This revision is intended to make the most recent information available to certificating authorities, noise certification applicants and other interested parties in a timely manner, aiming at achieving the highest degree of harmonization possible. The technical procedures and equivalent procedures described in this edition of the *Environmental Technical Manual* (ETM) are consistent with currently accepted techniques and modern instrumentation. In this respect, this edition of the ETM is compatible with Amendment 11 of Annex 16, Volume I. This revision and subsequent revisions that may be approved by the CAEP Steering Group will be posted on the ICAO website (http://www.icao.int/) under "publications" until the latest approved revision is submitted to CAEP for formal endorsement and subsequent publication by ICAO.

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

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ACRONYMS AND ABBREVIATIONS

AFM	Aeroplane flight manual
AMC	Acceptable means of compliance
APU	Auxiliary power unit
BPR	Bypass ratio
BVI	Blade vortex interaction
CAS	Calibrated airspeed
C/A	Coarse/Acquisition
CAEP	Committee on Aviation Environmental Protection
CDI	Course deviation indicator
CD-R	Recordable compact disc
CFR	Code of Federal Regulations
CG	Centre of gravity
CI	Confidence interval
CON	Conversion mode
CPA	Closest point of approach
DAT	Digital audiotape
DCC	Digital compact cassette
DGPS	Differential global positioning system
DMU	Distance measuring unit
EPNL	Effective perceived noise level
FAA	Federal Aviation Administration (United States)
FM	Frequency modulation
GDI	Glide slope deviation indicator
GM	Guidance material
GPS	Global positioning system
IAS	Indicated airspeed
ICD	Inflow control device
INS	Inertial navigation system
IOD	Issue of data
IRIG	Inter-Range Instrumentation Group
IRIG B	Inter-Range Instrumentation Group Standard Serial Time Code Format B
ISA	International standard atmosphere
LAAS	Local area augmentation system
LUP	Land-use planning
MAP	Manifold air pressure
MCP	Maximum continuous power
MO	Maximum operating

MD	Mini disc
MSL	Mean sea level
NAC	No-acoustical change
NMEA	National Marine Electronics Association
NPD	Noise-power-distance
OAT	Outside air temperature
PCM	Pulse code modulation
PLASI	Pulsating light approach slope indicator
PNL	Perceived noise level
PNLT	Tone corrected perceived noise level
PNLTM	Maximum tone corrected perceived noise level
R/C	Rate of climb
RFM	Rotorcraft flight manual
RH	Relative humidity
RTCA	Radio Technical Commission for Aeronautics
RTCM	Radio Technical Commission for Maritime Services
SAFM	Supplemental aeroplane flight manual
SARPs	Standards and Recommended Practices
SBV	Surge bleed valve
SEL	Sound exposure level
SFE	Static-to-flight equivalency
SHP	Shaft horse power
SNRS	Selectable noise reduction system
SPL	Sound pressure level
SR	Slant range
STC	Supplemental Type Certificate
STOL	Short take-off and landing
TAS	True airspeed
TSPI	Time-space-position information
UTC	Coordinated universal time
VASI	Visual approach slope indicator
VNRS	Variable noise reduction system
VTOL	Vertical take-off and landing
WGAR	Working group approved revision
WGS-84	World Geodetic Survey of 1984

NOMENCLATURE: SYMBOLS AND UNITS

Note.— Many of the following definitions and symbols are specific to aircraft noise certification. Some of the definitions and symbols may also apply to purposes beyond aircraft noise certification.

Symbol	*Unit*	*Meaning*
antilog	—	*Antilogarithm to the base 10.*
Best R/C	m/s	*Best rate of climb*. The certificated maximum take-off rate of climb at the maximum power setting and engine speed.
c	m/s	*Speed of sound.* The speed of sound at test conditions.
c_A	m/s	*Speed of sound at aeroplane height.* The speed of sound corresponding to the temperature for an ICAO Standard Atmosphere + 10° C at the aeroplane test height above mean sea level. (See noise data adjustments for test at high altitude test sites, section 4.3.2.3.)
c_B	m/s	*Speed of sound at equivalent aeroplane height.* The speed of sound corresponding to the temperature for an ICAO Standard Atmosphere + 10° C at the aeroplane test height above mean sea level minus the test-site elevation. (See noise data adjustments for test at high altitude test sites, section 4.3.2.3.)
c_{HR}	m/s	*Reference speed of sound.* The reference speed of sound corresponding to the ambient temperature for a standard day at the aeroplane reference height above mean sea level. (See no-acoustical change guidance for propeller-driven aeroplanes, section 5.2.5.3.)
c_R	m/s	*Reference speed of sound*. Speed of sound at reference conditions.
C	dB	*Tone correction factor.* The factor to be added to the PNL of a given spectrum to account for the presence of spectral irregularities such as tones.
CPA	m	*Closest point of approach.* The distance between the aircraft and the microphone at the closest point on the flight path to the microphone. (See determination of noise geometry, section 4.3.1.2.)
CPA_R	m	*Reference closest point of approach.* The distance between the aircraft and the reference microphone at the closest point on the reference flight path to the reference microphone. (See determination of noise geometry, section 4.3.1.2.)
CPA_{OHR}	m	A distance used as an intermediate calculation in the determination of aircraft noise geometry. (See determination of noise geometry, section 4.3.1.2.)

Symbol	*Unit*	*Meaning*
d	s	*Duration.* The time interval between 10 dB-down points in the discrete measured PNLT time history. (See guidelines on adjustment of helicopter land-use planning noise data, section 8.3.1.)
d_R	s	*Reference duration.* For a non-constant airspeed reference flight condition, the time interval between the positions on the reference flight path corresponding to the 10 dB-down points in the discrete measured PNLT time history. (See guidelines on adjustment of helicopter land-use planning noise data, section 8.3.1.)
D	m	*Diameter*. Propeller or rotor diameter.
D_{15}	m	*Take-off distance.* The take-off distance required for an aeroplane to reach 15 m height above ground level. (See no-acoustical change guidance for propeller-driven aeroplanes, section 5.2.5.3.)
D_{50}	ft	*Take-off distance.* The take-off distance required for an aeroplane to reach 50 m height above ground level. (See propeller-driven aeroplane source noise adjustment, section 5.2.5.3.)
e	—	*Euler's number*. The mathematical constant that is the base number of the natural logarithm, approximately 2.78183.
EPNL	EPNdB	*Effective perceived noise level.* A single-number evaluator for an aircraft pass-by, accounting for the subjective effects of aircraft noise on human beings, consisting of an integration over the noise duration of the perceived noise level (PNL) adjusted for spectral irregularities (PNLT), normalized to a reference duration of 10 seconds. (See Appendix 2, section 4.1, of the Annex for specifications.)
$EPNL_A$	EPNdB	*Approach EPNL*. Effective perceived noise level at the aeroplane approach reference measurement points. (See Attachment A of the Annex.)
$EPNL_F$	EPNdB	*Flyover EPNL*. Effective perceived noise level at the aeroplane flyover reference measurement points. (See Attachment A of the Annex.)
$EPNL_L$	EPNdB	*Lateral EPNL*. Effective perceived noise level at the aeroplane lateral reference measurement points. (See Attachment A of the Annex.)
f	Hz	*Frequency*. The nominal geometric mean frequency of a one-third octave band.
f_{DOPP}	Hz	*Doppler-shifted frequency*. The observed frequency at the receiver of an aeroplane noise source that results from the motion of the aeroplane relative to the microphone due to Doppler frequency shift. (See identification of spectral irregularities, section 4.3.2.2.)

Symbol	*Unit*	*Meaning*
f_{flight}	Hz	*Flight frequency*. The predicted, Doppler-shifted frequency of an aeroplane noise source other than jet noise measured during static testing that results from the motion of the aeroplane relative to the microphone. (See static engine noise tests, section 4.2.1.3.)
f_{static}	Hz	*Static frequency*. The frequency of an aeroplane noise source other than jet noise measured during static testing. (See static engine noise tests, section 4.2.1.3.)
F	dB	*Delta-dB.* The difference between the original sound pressure level and the final broadband sound pressure level of a one-third octave band in a given spectrum.
F_N	N	*Engine thrust.* Actual engine net thrust per engine.
FPDdist	m	A distance used as an intermediate calculation in the determination of aircraft noise geometry. (See determination of noise geometry, section 4.3.1.2.)
$\text{FPDdist}_{\text{R}}$	m	A distance used as an intermediate calculation in the determination of aircraft noise geometry. (See determination of noise geometry, section 4.3.1.2.)
FPInc_{R}	m	A distance used as an intermediate calculation in the determination of aircraft noise geometry. (See determination of noise geometry, section 4.3.1.2.)
F1	—	*Directivity correction factor*. An adjustment to the jet source noise based on the sound emission angle of the one-half-second spectrum being corrected. (See noise data adjustments for test at high altitude test sites, section 4.3.2.3.)
F2	—	*Frequency correction factor*. An adjustment to the jet source noise based on the band number of the one-third octave band sound pressure level being corrected. (See noise data adjustments for test at high altitude test sites, section 4.3.2.3.)
Galt	m	A distance used as an intermediate calculation in the determination of aircraft noise geometry. (See determination of noise geometry, section 4.3.1.2.)
GCPA	m	A distance used as an intermediate calculation in the determination of aircraft noise geometry. (See determination of noise geometry, section 4.3.1.2.)
Ginc	m	A distance used as an intermediate calculation in the determination of aircraft noise geometry. (See determination of noise geometry, section 4.3.1.2.)
Gnorm	m	A distance used as an intermediate calculation in the determination of aircraft noise geometry. (See determination of noise geometry, section 4.3.1.2.)
H	m	*Height*. The aircraft height when overhead or abeam of the centre microphone.
H_{MIC}	m	*Microphone height.* The height of the microphone above the ground. (See determination of noise geometry, section 4.3.1.2.)

Symbol	*Unit*	*Meaning*
H_{MICR}	m	*Reference microphone height.* The height of the reference microphone, 1.2 m, above the reference ground plane. (See determination of noise geometry, section 4.3.1.2.)
H_R	m	*Reference height*. The reference aircraft height when overhead or abeam of the centre microphone.
i	—	*Frequency band index.* The numerical indicator that denotes any one of the 24 one-third octave bands with nominal geometric mean frequencies from 50 to 10 000 Hz.
i_{LGB}	—	*Last good band index.* Index of the highest frequency unmasked one-third octave band in a spectrum. (See background noise adjustment procedure.)
k	—	*Doppler adjustment constant.* A constant used in the calculation of flight sound pressure level from static engine test data. (See static engine noise tests, section 4.2.1.3.)
k	—	*Time increment index*. The numerical indicator that denotes any one of the 0.5 second spectra in a noise time history. For the integrated method, the adjusted time increment associated with each value of k will likely vary from the original 0.5 second time increment when projected to reference conditions.
k_F	—	*First time increment identifier*. Index of the first 10 dB-down point in the discrete measured PNLT time history.
k_{FR}	—	*Reference first time increment identifier*. Index of the first 10 dB-down point in the discrete PNLT time history for the integrated method.
k_L	—	*Last time increment identifier*. Index of the last 10 dB-down point in the discrete measured PNLT time history.
k_{LR}	—	*Reference last time increment identifier*. Index of the last 10 dB-down point in the discrete PNLT time history for the integrated method.
k_M	—	*PNLTM time increment identifier*. Time increment index of PNLTM.
k_{M2}	—	*Secondary peak time increment identifier*. Index of the maximum secondary peak. (See determination of the Δ_{peak} adjustment term, section 4.3.1.3.5.)
log	—	*Logarithm to the base 10.*
log $n(a)$	—	*Noy discontinuity coordinate.* The log n value of the intersection point of the straight lines representing the variation of SPL with log n. (See mathematical formulation of noy tables, Appendix 2, section 4.7, of the Annex.)

Symbol	*Unit*	*Meaning*
L_{AE}	dB SEL	*Sound exposure level (SEL)*. A single event noise level for an aircraft pass-by, consisting of an integration over the noise duration of the A-weighted sound level (dB(A)), normalized to a reference duration of 1 second. (See Appendix 4, section 3, of the Annex for specifications.)
L_{AS}	dB(A)	*Slow A-weighted sound level*. Sound level with frequency weighting A and time weighting S for a specified instance in time.
L_{ASmax}	dB(A)	*Maximum Slow A-weighted sound level*. The maximum value of L_{AS} over a specified time interval.
L_{ASmaxR}	dB(A)	*Reference maximum Slow A-weighted sound level.* The maximum value of L_{AS} over a specified time interval corrected to reference conditions.
$LIMIT_A$	EPNdB	*Approach EPNL limit*. The maximum permitted noise level at the aeroplane approach reference measurement points. (See Attachment A of the Annex.)
$LIMIT_F$	EPNdB	*Flyover EPNL limit*. The maximum permitted noise level at the aeroplane flyover reference measurement points. (See Attachment A of the Annex.)
$LIMIT_L$	EPNdB	*Lateral EPNL limit*. The maximum permitted noise level at the aeroplane lateral reference measurement points. (See Attachment A of the Annex.)
m	—	*Closest valid band time increment identifier*. Index of the nearest record in time that contains a valid level for a given band. (See background noise adjustment procedure, section 3.6.3.)
M	—	*Aircraft Mach number*. The test airspeed of the aircraft divided by the test speed of sound.
M	—	*Noy inverse slope.* The reciprocals of the slopes of straight lines representing the variation of SPL with log n. (See mathematical formulation of noy tables, Appendix 2, section 4.7, of the Annex.)
Malt	m	A distance used as an intermediate calculation in the determination of aircraft noise geometry. (See determination of noise geometry, section 4.3.1.2.)
M_{AT}	—	*Helicopter rotor advancing blade tip Mach number.* The sum of the test rotational tip speed of a rotor and the test airspeed of the helicopter, divided by the test speed of sound.
M_{ATR}	—	*Helicopter rotor reference advancing blade tip Mach number*. The sum of the reference rotor rotational tip speed and the reference speed of the helicopter, divided by the reference speed of sound.
M_H	—	*Propeller helical tip Mach number*. The square root of the sum of the square of the propeller test rotational tip speed and the square of the test airspeed of the aeroplane, divided by the test speed of sound.

Symbol	*Unit*	*Meaning*
M_{HR}	—	*Propeller reference helical tip Mach number*. The square root of the sum of the square of the propeller reference rotational tip speed and the square of the reference speed of the aeroplane, divided by the reference speed of sound.
n	noy	*Perceived noisiness.* The perceived noisiness of a one-third octave band sound pressure level in a given spectrum. (See mathematical formulation of noy tables, Appendix 2, section 4.7, of the Annex.)
N	rpm	*Propeller speed.* (See no-acoustical change guidance for propeller-driven aeroplanes, section 5.2.5.3.)
N	noy	*Total perceived noisiness.* The total perceived noisiness of a given spectrum calculated from the 24 values of n. (See mathematical formulation of noy tables, Appendix 2, section 4.7, of the Annex.)
N_1	rpm	*Compressor speed.* The turbine engine low pressure compressor first stage fan speed.
N_{1C}	rpm	*Corrected compressor speed*. The turbine engine low pressure compressor first stage fan speed corrected to sea level standard day conditions. (See noise data adjustments for test at high altitude test sites, section 4.3.2.3.)
p	—	*Aircraft position time increment index.* Index of a point in the discrete measured aircraft position time history before interpolation to the sound emission time of point k in a noise time history. (See determination of noise geometry, section 4.3.1.2.)
p_A	Pa	*A-weighted sound pressure*. The root-mean-squared sound pressure with frequency weighting A for a specified instance in time, used to calculate A-weighted sound level.
p_{HR}	hPa	*Reference pressure.* The standard day ambient pressure at the aeroplane reference height above mean sea level. (See no-acoustical change guidance for propeller-driven aeroplanes, section 5.2.5.3.)
p_0	Pa	*Reference sound pressure*. The reference root-mean-squared sound pressure of 20 μPa.
P	kW or SHP	*Engine Power.* Engine power generated under test ambient temperature and air density conditions.
PNL	PNdB	*Perceived noise level.* A perception-based noise evaluator representing the subjective effects of broadband noise received at a given point in time during an aircraft pass-by. It is the noise level empirically determined to be equally as noisy as a 1 kHz one-third octave band sample of random noise. (See Appendix 2, section 4.2, of the Annex for specifications.)
PNLT	TPNdB	*Tone-corrected perceived noise level.* The value of the PNL of a given spectrum adjusted for spectral irregularities.

Symbol	*Unit*	*Meaning*
$PNLT_R$	TPNdB	*Reference tone-corrected perceived noise level.* The value of PNLT adjusted to reference conditions.
PNLTM	TPNdB	*Maximum tone-corrected perceived noise level.* The maximum value of PNLT in a specified time history, adjusted for the bandsharing adjustment Δ_B.
$PNLTM_R$	TPNdB	*Reference maximum tone-corrected perceived noise level.* The maximum value of $PNLT_R$ in a specified time history, adjusted for the bandsharing adjustment Δ_B in the simplified method and Δ_{BR} in the integrated method.
P_0	kW or SHP	*Reference engine power. Engine power generated under reference* ambient temperature and air density conditions.
R	J/kgK	*Gas constant.* Gas constant for dry air, 287.04 J/kgK.
R/C	m/s	*Rate of climb*. The take-off rate of climb at the test power setting and engine speed.
RH	%	*Relative humidity.* The ambient atmospheric relative humidity.
s	dB	*Slope of sound pressure level.* The change in level between adjacent one-third octave band sound pressure levels in a given spectrum. (See correction for spectral irregularities, Appendix 2, section 4.3, of the Annex.)
S	—	*Strouhal number.* A dimensionless number describing oscillating flow mechanisms.
s'	dB	*Adjusted slope of sound pressure level.* The change in level between adjacent adjusted one-third octave band sound pressure levels in a given spectrum. (See correction for spectral irregularities, Appendix 2, section 4.3, of the Annex.)
$\bar{s}$	dB	*Average slope of sound pressure level.* (See correction for spectral irregularities, Appendix 2, section 4.3, of the Annex.)
SPL	dB	*Sound pressure level.* The level of sound at any instant in time that occurs in a specified frequency range. The level is calculated as ten times the logarithm to the base 10 of the ratio of the time-mean-square pressure of the sound to the square of the reference sound pressure of 20 μPa. *Note: — Typical aircraft noise certification usage refers to a specific one-third octave band, e.g. SPL(i,k) for the i-th band of the k-th spectrum in an aircraft noise time-history.*
SPL(a)	dB	*Noy discontinuity level.* The SPL value at the discontinuity coordinate of the straight lines representing the variation of SPL with log n. (See mathematical formulation of noy tables, Appendix 2, section 4.7, of the Annex.)

Symbol	*Unit*	*Meaning*
SPL(*b*) SPL(*c*)	dB	*Noy intercept levels.* The intercepts on the SPL-axis of the straight lines representing the variation of SPL with log *n*. (See mathematical formulation of noy tables, Appendix 2, section 4.7, of the Annex.)
SPL(*d*)	dB	*Noy discontinuity level*. The SPL value at the discontinuity coordinate where log *n* equals −1. (See mathematical formulation of noy tables, Appendix 2, section 4.7, of the Annex.)
SPL(*e*)	dB	*Noy discontinuity level*. The SPL value at the discontinuity coordinate where log *n* equals log 0.3. (See mathematical formulation of noy tables, Appendix 2, section 4.7, of the Annex.)
SPL′	dB	*Adjusted sound pressure level.* The first approximation to broadband sound pressure level in a one-third octave band of a given spectrum. (See correction for spectral irregularities, Appendix 2, section 4.3, of the Annex.)
SPL″	dB	*Final broadband sound pressure level.* The second and final approximation to broadband sound pressure level in a one-third octave band of a given spectrum. (See correction for spectral irregularities, Appendix 2, section 4.3, of the Annex.)
SPL_{flight}	dB	*Flight sound pressure level.* A measured static one-third octave band sound pressure level adjusted for changes that result from the motion of the aeroplane relative to the microphone due to Doppler shift. (See static engine noise tests, section 4.2.1.3.)
SPL_{static}	dB	*Static sound pressure level.* A measured static one-third octave band sound pressure level. (See static engine noise tests, section 4.2.1.3.)
SPL_X	dB	*Extrapolated sound pressure level.* Frequency-extrapolated level for masked band *i* and spectral record *k*. (See background noise adjustment procedure, section 3.6.3.)
SPL_R	dB	*Reference sound pressure level*. The one-third octave band sound pressure levels adjusted to reference conditions. (See adjustments to spectrum at PNLTM, Appendix 2, section 8.3.2, of the Annex.)
SPL_S	dB	*Slow-weighted sound pressure level*. The value of one-third octave band sound pressure levels with time weighting S applied. (See analysis systems, Appendix 2, section 3.7.5, of the Annex.)
SR	m	*Slant range.* The distance between the aircraft and the microphone at a given point in time. The related term *sound propagation distance* is the slant range between a sound emission point on the measured flight path and the microphone.

Symbol	*Unit*	*Meaning*
SR_R	m	*Reference slant range.* The distance between the aircraft on the reference flight path and the reference microphone at a given point in time. The related term *reference sound propagation distance* is the slant range between a sound emission point on the reference flight path and the reference microphone location.
t	s	*Elapsed time.* The length of time measured from a reference zero.
T	°C	*Temperature.* The ambient atmospheric temperature.
t_E	s	*Sound emission time.* The time that the sound was emitted by the aircraft.
t_{ER}	s	*Reference sound emission time.* The time that the sound would have been emitted by the aircraft under reference conditions.
t_m	s	*Measurement time.* The time that the sound was measured and output from the analyser, adjusted by −0.75 s.
t_R	s	*Reference reception time*. The reference time of reception calculated from time of reference aircraft position and distance between aircraft and microphone used in the integrated procedure.
T_{HR}	°C	*Temperature at reference aeroplane height.* The standard day ambient temperature at the aeroplane reference height above mean sea level. (See no-acoustical change guidance for propeller-driven aeroplanes, section 5.2.5.3.)
t_{rec}	s	*Sound reception time.* The time of sound reception, calculated by adding to the sound emission the sound propagation time.
t_0	s	*Reference duration*. The length of time used as a reference in the integration equation for computing EPNL, where $t_0 = 10$ s.
t_1	s	*Time of first 10 dB-down point*. The time of the first 10 dB-down point in a continuous function of time. (See k_F.)
t_2	s	*Time of last 10 dB-down point*. The time of the last 10 dB-down point in a continuous function of time. (See k_L.)
T_0	K	*Reference temperature.*
u	m/s	*Wind speed along-track component*. The component of the wind speed vector along the reference ground track. (See test environment, Appendix 2, section 2.2.1, of the Annex.)
U	m/s	*Equivalent relative jet velocity.* The difference between the equivalent jet velocity V_j and the aeroplane test velocity V. (See noise data adjustments for test at high altitude test sites, section 4.3.2.3.)

Symbol	*Unit*	*Meaning*
U_A	m/s	*Equivalent relative jet velocity at condition A*. The equivalent relative jet velocity for the condition where V_j is determined at the corrected engine fan speed for standard acoustical day atmospheric conditions at the aeroplane test height above mean sea level. (See noise data adjustments for test at high altitude test sites, section 4.3.2.3.)
U_B	m/s	*Equivalent relative jet velocity at condition B*. The equivalent relative jet velocity for the condition where V_j is determined at the corrected engine fan speed for standard acoustical day atmospheric conditions at the aeroplane test height above mean sea level minus the test site elevation. (See noise data adjustments for test at high altitude test sites, section 4.3.2.3.)
v	m/s	*Wind speed cross-track component*. The component of the wind speed vector horizontally perpendicular to the reference ground track. (See test environment, Appendix 2, section 2.2.1, of the Annex.)
V_{AR}	km/h	*Adjusted reference speed*. On a non-standard test day, the helicopter reference speed adjusted to achieve the same advancing tip Mach number as the reference speed at reference conditions.
V_{CAS}	km/h	*Calibrated airspeed.* The indicated airspeed of an aircraft, corrected for position and instrument error but uncorrected for adiabatic compressible flow for the test altitude. Calibrated airspeed is equal to true airspeed in standard atmosphere at sea level.
V_{CON}	km/h	*Maximum airspeed in conversion mode*. The never-exceed airspeed of a tilt-rotor when in conversion mode.
V_G	km/h	*Ground speed*. The aircraft true velocity relative to the ground.
V_{GR}	km/h	*Reference ground speed*. The aircraft true velocity relative to the ground in the direction of the ground track under reference conditions. V_{GR} is the horizontal component of the reference aircraft speed V_R.
V_H	km/h	*Maximum airspeed in level flight*. The maximum airspeed of a helicopter in level flight when operating at maximum continuous power.
V_{MCP}	km/h	*Maximum airspeed in level flight*. The maximum airspeed of a tilt-rotor in level flight when operating in aeroplane mode at maximum continuous power.
V_{MO}	km/h	*Maximum operating airspeed*. The maximum operating limit airspeed of a tilt-rotor that may not be deliberately exceeded.
V_{NE}	km/h	*Never exceed airspeed*. The maximum operating limit airspeed that may not be deliberately exceeded.

Symbol	*Unit*	*Meaning*
V_R	km/h	*Reference speed*. The aircraft true velocity at reference conditions in the direction of the reference flight path. *Note:— This symbol should not be confused with the symbol commonly used for aeroplane take-off rotation speed.*
V_{REF}	km/h	*Reference landing airspeed*. The speed of the aeroplane, in a specific landing configuration, at the point where it descends through the landing screen height in the determination of the landing distance for manual landings.
V_S	km/h	*Stalling airspeed*. The minimum steady airspeed in the landing configuration.
V_{tip}	m/s	*Tip speed*. The rotational speed of a rotor or propeller tip at test conditions, excluding the aircraft velocity component.
V_{tipR}	m/s	Reference tip speed. The rotational speed of a rotor or propeller tip at reference conditions, excluding the aircraft velocity component.
V_{IAS}	km/h	*Indicated airspeed.* The aircraft velocity as measured by a pitot-static airspeed system calibrated to reflect standard atmosphere adiabatic compressible flow at sea level uncorrected for airspeed system errors.
V_j	m/s	*Equivalent engine jet velocity.* (See noise data adjustments for test at high altitude test sites, section 4.3.2.3.)
V_{TAS}	km/h	*True airspeed.* The aircraft true velocity relative to the air in the direction of the flight path.
V_Y	km/h	*Speed for best rate of climb*. The test airspeed for best take-off rate of climb.
V_2	km/h	*Take-off safety speed*. The minimum airspeed for a safe take-off.
x	m	*Downstream distance.* The distance downstream from the engine nozzle exit. (See static engine noise tests.)
X	m	*Aircraft position along the ground track*. The position coordinate of the aircraft along the x-axis at a specific point in time.
X_E	m	*Aircraft X position at time of sound emission*. The position coordinate of the aircraft along the x-axis when the sound was emitted by the aircraft. (See determination of noise geometry, section 4.3.1.2.)
X_{MIC}	m	*Microphone X location.* The longitudinal distance along the reference ground track between the microphone and the coordinate system origin. (See determination of noise geometry, section 4.3.1.2.)
X_{MICR}	m	*Reference microphone X location.* The longitudinal distance along the reference ground track between the reference microphone location and the coordinate system origin. (See determination of noise geometry, section 4.3.1.2.)

Symbol	*Unit*	*Meaning*
X_{OH}	m	*Aircraft X position at overhead*. The position coordinate of the aircraft along the x-axis when passing over the centre microphone. (See determination of noise geometry, section 4.3.1.2.)
Y	m	*Lateral aircraft position relative to the reference ground track*. The position coordinate of the aircraft along the y-axis at a specific point in time.
Ydis	m	A distance used as an intermediate calculation in the determination of aircraft noise geometry. (See determination of noise geometry, section 4.3.1.2.)
Y_E	m	*Aircraft Y position at time of sound emission*. The position coordinate of the aircraft along the y-axis when the sound was emitted by the aircraft. (See determination of noise geometry, section 4.3.1.2.)
Y_{MIC}	m	*Microphone Y location.* The lateral distance between the microphone and the reference ground track. (See determination of noise geometry, section 4.3.1.2.)
Y_{MICR}	m	*Reference microphone Y location.* The lateral distance between the reference microphone location and the reference ground track. (See determination of noise geometry, section 4.3.1.2.)
Y_{OH}	m	*Aircraft Y position at overhead*. The position coordinate of the aircraft along the y-axis when passing over the centre microphone. (See determination of noise geometry, section 4.3.1.2.)
Z	m	*Vertical aircraft position relative to the reference ground track*. The position coordinate of the aircraft along the z-axis at a specific point in time.
Z_E	m	*Aircraft Z position at time of sound emission*. The position coordinate of the aircraft along the z-axis when the sound was emitted by the aircraft. (See determination of noise geometry, section 4.3.1.2.)
Zinc	m	A distance used as an intermediate calculation in the determination of aircraft noise geometry. (See determination of noise geometry, section 4.3.1.2.)
Z_{MIC}	m	*Microphone Z location.* The height of the ground at the microphone location relative to the reference ground track. (See determination of noise geometry, section 4.3.1.2.)
Z_{MICR}	m	*Reference microphone Z location.* The height of the ground at the reference microphone location relative to the reference ground track. (See determination of noise geometry, section 4.3.1.2.)
Z_{OH}	m	*Aircraft Z position at overhead*. The position coordinate of the aircraft along the z-axis when passing over the centre microphone. (See determination of noise geometry, section 4.3.1.2.)

Symbol	*Unit*	*Meaning*
Z_{OHR}	m	*Reference aircraft Z position at overhead*. The reference position coordinate of the aircraft along the z-axis when passing over the centre microphone. (See determination of noise geometry, section 4.3.1.2.)
α	dB/100 m	*Test atmospheric absorption coefficient.* The sound attenuation rate due to atmospheric absorption that occurs in a specified one-third octave band for the measured ambient temperature and relative humidity.
α_R	dB/100 m	*Reference atmospheric absorption coefficient.* The sound attenuation rate due to atmospheric absorption that occurs in a specified one-third octave band for a reference ambient temperature and relative humidity.
γ	degrees	*Climb/descent angle.* If positive, the average climb angle during the take-off condition. If negative, the average descent angle during the approach condition. (See determination of noise geometry, section 4.3.1.2.)
γ_R	degrees	*Reference climb/descent angle.* If positive, the reference climb angle during the take-off condition. If negative, the reference descent angle during the approach condition. (See determination of noise geometry, section 4.3.1.2.)
δ_{amb}	—	*Static pressure ratio.* Ratio of the static air pressure at the aeroplane test height above mean sea level to the standard day air pressure at mean sea level of 101.325 kPa.
δt_{prop}	s	*Sound propagation time.* The time interval between the sound emission time and the sound reception time, calculated from the sound propagation distance (slant range) and the speed of sound.
δt_{propR}	s	*Reference sound propagation time.* The time interval between the reference sound emission time and the sound reception time, calculated from the reference sound propagation distance (reference slant range) and the reference speed of sound.
δt_R	s	*Reference time increment*. The effective duration of a time increment between reference reception times associated with PNLT points used in the integrated method.
Δ_A	EPNdB	*Approach condition adjustment.* The difference between flight datum and derivative aeroplane EPNL at the power requirement of the derivative aeroplane at the approach condition. (See static engine noise tests, section 4.2.1.3.)
Δ_B	TPNdB	*Bandsharing adjustment*. The adjustment to be added to the maximum PNLT to account for possible suppression of a tone due to one-third octave bandsharing of that tone. PNLTM is equal to the maximum PNLT plus Δ_B.
Δ_{BR}	TPNdB	*Reference bandsharing adjustment*. The adjustment to be added to the maximum $PNLT_R$ in the integrated method to account for possible suppression of a tone due to one-third octave bandsharing of that tone. $PNLTM_R$ is equal to the maximum $PNLT_R$ plus $\Delta_{BR.}$

Symbol	*Unit*	*Meaning*
Δ_L	EPNdB	*Lateral condition adjustment.* The difference between flight datum and derivative aeroplane EPNL at the power requirement of the derivative aeroplane at the lateral condition. (See static engine noise tests, section 4.2.1.3.)
ΔL	dB	*Total noise level adjustment.* The sum of the adjustments to be added to L_{ASmax} when analytically calculating the change in noise level for the purpose of demonstrating a no-acoustical change to a small propeller-driven aeroplane. (See no-acoustical change guidance for propeller-driven aeroplanes, section 5.2.5.3.)
Δ_{peak}	TPNdB	*Peak adjustment*. The adjustment to be added to the measured EPNL for when the PNLT for a secondary peak, identified in the calculation of EPNL from measured data and adjusted to reference conditions, is greater than the PNLT for the adjusted PNLTM spectrum.
Δs	dB	*Change in slope of sound pressure level.* (See mathematical formulation of noy tables, Appendix 2, section 4.7, of the Annex.)
ΔSPL	dB	*Jet source noise adjustment.* The adjustment to be added to the measured one-third octave band sound pressure levels for each one-half-second spectrum in the integrated method or the PNLTM spectrum in the simplified method to account for jet source noise level changes when tests are conducted at high altitude test sites. (See noise data adjustments for test at high altitude test sites, section 4.3.2.3.)
Δt	s	*Time increment.* The equal time increment between one-third octave band spectra, where $\Delta t = 0.5$ s.
Δ_T	EPNdB	*Take-off condition adjustment.* The difference between flight datum and derivative aeroplane EPNL at the power requirement and altitude of the derivative aeroplane at the take-off condition. (See static engine noise tests, section 4.2.1.3.)
Δ_1	TPNdB	*PNLTM adjustment.* In the simplified adjustment method, the adjustment to be added to the measured EPNL to account for noise level changes due to differences in atmospheric absorption and noise path length between test and reference conditions at PNLTM. For propeller aeroplanes, the adjustment to be added to L_{ASmax} to account for noise level changes due to the difference between test and reference aeroplane heights.
Δ_{1D}	TPNdB	*PNLTM adjustment.* For the purpose of land-use planning data for helicopters tested under Chapter 11 of the Annex, the duration adjustment component of Δ_1. (See guidelines on adjustment of helicopter land-use planning noise data, section 8.3.1.)

Symbol	*Unit*	*Meaning*
Δ_{1SS}	TPNdB	*PNLTM adjustment.* For the purpose of land-use planning data, the spherical spreading adjustment component of Δ_1. (See guidelines on adjustment of helicopter land-use planning noise data, section 8.3.1.)
Δ_2	TPNdB	*Duration adjustment.* In the simplified adjustment method, the adjustment to be added to the measured EPNL to account for noise level changes due to the change in noise duration caused by differences between test and reference aircraft speed and position relative to the microphone.
Δ_3	TPNdB	*Source noise adjustment.* In the simplified or integrated adjustment method, the adjustment to be added to the measured EPNL to account for noise level changes due to differences in source noise generating mechanisms between test and reference conditions.
Δ_4	dB	*Atmospheric absorption adjustment*. For propeller aeroplanes, the adjustment to be added to the measured L_{ASmax} for noise level changes due to the change in atmospheric absorption caused by the difference between test and reference aeroplane heights.
Δ_ϕ	dB	*Inflow angle noise adjustment.* For propeller aeroplanes, the adjustment to be added to L_{ASmax} to account for noise level changes due to a change in propeller inflow angle between a modified aeroplane and a parent aeroplane. (See no-acoustical change guidance for propeller-driven aeroplanes, section 5.2.5.3.)
θ	degrees	*Sound emission angle.* The angle between the flight path and the direct sound propagation path to the microphone. The angle is identical for both the measured and reference flight paths.
θ_R	degrees	*Reference sound emission angle.* The angle between the reference flight path and direct sound propagation path to the reference microphone. The angle is identical for both the measured and reference flight paths.
θ_{T2}	—	*Temperature ratio*. The ratio of the static air temperature in Kelvin at the aeroplane test height above mean sea level to the standard day air temperature at mean sea level of 288.15 K.
μ	—	*Engine noise performance parameter.* For jet aeroplanes, typically the normalized low pressure fan speed, normalized engine thrust, or engine pressure ratio used in the calculation of the source noise adjustment.
ρ_A	kg/m^3	*Density.* The standard acoustical day density at the aeroplane test height above mean sea level. (See noise data adjustments for test at high altitude test sites, section 4.3.2.3.)
ρ_B	kg/m^3	*Density.* The standard acoustical day density at the aeroplane test height above mean sea level minus the test-site elevation. (See noise data adjustments for test at high altitude test sites, section 4.3.2.3.)

Symbol	*Unit*	*Meaning*
ρ_{HR}	kg/m^3	*Reference density.* The standard day density at the aeroplane reference height above mean sea level. (See no-acoustical change guidance for propeller-driven aeroplanes, section 5.2.5.3.)
ϕ	degree	*Propeller inflow angle.* The angle between the propeller blade relative airflow and the propeller rotational plane, typically measured at the 75% radial station. (See no-acoustical change guidance for propeller-driven aeroplanes, section 5.2.5.3.)
χ	degrees	*Lateral cross-track angle.* The horizontal angle between the average ground track and the reference ground track. (See determination of noise geometry, section 4.3.1.2.)
ψ	degrees	*Elevation angle.* The angle between the sound propagation path and a horizontal plane passing through the microphone, where the sound propagation path is defined as a line between a sound emission point on the measured flight path and the microphone diaphragm.
ψ_R	degrees	*Reference elevation angle.* The angle between the reference sound propagation path and a horizontal plane passing through the reference microphone location, where the reference sound propagation path is defined as a line between a sound emission point on the reference flight path and the reference microphone diaphragm.

Chapter 1

INTRODUCTION

1.1 PURPOSE

The aim of this manual is to promote uniformity of implementation of the technical procedures of Annex 16 — *Environmental Protection,* Volume I — *Aircraft Noise,* and to provide guidance to certificating authorities and applicants regarding the intended meaning and stringency of the Standards in the current edition of the Annex and the specific procedures that are deemed acceptable in demonstrating compliance with those Standards.

This manual provides guidance material relating to the requirements of Appendices 2, 3, 4 and 6 of the Annex as appropriate. Those appendices describe the noise evaluation methods for compliance with the corresponding chapters of the Annex for jet aeroplanes, propeller-driven heavy and light aeroplanes, helicopters and tilt-rotors.

1.2 DOCUMENT STRUCTURE

The basic framework of this manual is structured to provide various forms of noise certification guidance material for these aircraft. Chapter 2 provides general information, Chapter 3 provides guidance that is common to more than one type of aircraft and subsequent chapters provide guidance unique to different aircraft types.

The general format of the guidance material presented in Chapters 4 through 8 includes three types of information: explanatory information, equivalent procedures and technical procedures, which are described in the following sections.

1.3 EXPLANATORY INFORMATION

Explanatory information has the following purpose:

a) explains the language of the Annex noise Standards;

b) states current policies of certificating authorities regarding compliance with the Annex; and

c) provides information on critical issues concerning approval of applicants' compliance methodology proposals.

Explanatory information may take the form of either:

a) guidance material (GM), which helps to illustrate the meaning of a specification or requirement; or

b) acceptable means of compliance (AMC), which illustrates a means, but not the only means, by which a requirement specified in Annex 16, Volume I, can be met. It may contain reference to an equivalent procedure described in this manual.

The GM and AMC numbers refer to the appendix and section number of Annex 16, Volume I, to which they relate. For example, GM A2 2.2.1 is guidance material concerning section 2.2.1 of Appendix 2 of Annex 16, Volume I.

GM and AMC titles appearing in square brackets denote the general subject matter of the text and not specific Annex 16 titles, for example [Test site selection]. An index of GM and AMC numbers is provided at the end of this document.

1.4 EQUIVALENT PROCEDURES

An equivalent procedure is a test or analysis procedure which, while differing from one specified in the Annex, in the technical judgement of the certificating authority, yields effectively the same noise levels as the specified procedure.

Equivalent procedures fall into two broad categories:

a) those which are generally applicable; and

b) 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 be appropriate only for jet aeroplanes and not for turboprop aeroplanes.

Typical applications of equivalent procedures requested by applicants are to:

a) use previously acquired certification test data for the aircraft type;

b) permit and encourage more reliable demonstration of small level differences among derived versions of aircraft; and

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

1.5 TECHNICAL PROCEDURES

A technical procedure is a test or analysis procedure not defined in detail in the Annex but which certificating authorities have approved as being acceptable for compliance with the general provisions of the Annex.

The procedures described in the Annex must be used unless an equivalent procedure or alternative technical procedure is approved by the certificating authority. Procedures should not be considered as limited only to those described herein, as this manual will be expanded as new procedures are developed. Also, their presentation does not infer limitation of their application or commitment by certificating authorities to their further use.

1.6 CONVERSION OF UNITS

Conversions of some non-critical numerical values between U.S. Customary (English) and SI units are shown in the context of acceptable approximations.

1.7 REFERENCES

Unless otherwise specified, references throughout this document to "the Annex" relate to Annex 16 to the Convention on International Civil Aviation (*Environmental Protection*), Volume I (*Aircraft Noise*), Seventh Edition, Amendment 11.

References to sections of this manual are defined only by the section number to which they refer. References to documents other than the Annex are numbered sequentially (Reference 1, Reference 2, etc.). A list of these documents is provided in Appendix 1 to this manual, and a suggested bibliography is provided in Appendix 2.

Chapter 2

GENERAL GUIDELINES

2.1 APPLICABILITY OF CURRENT AND PREVIOUS AMENDMENTS TO ANNEX 16, VOLUME I

Since the publication of the first edition of Annex 16 many amendments and new editions have been published. Each amendment and new edition retains the older chapters (e.g. Chapter 2), even though they may no longer be applicable to new types of aircraft. Since each new amendment or edition succeeds the previous version, the applicability provisions of each chapter are in principle retained, thus preserving their continuity.

The first section of Chapters 2, 3, 4, 5, 6, 8, 10, 11, 12, 13 and 14 of the Annex, together with the paragraphs concerning applicability in Chapter 1 of the Annex, define the applicability of each chapter. Their applicability to new types is determined by the date the application for the Type Certificate was submitted to the State of Design.

In many instances the chapter and maximum noise levels so determined for a new type are also applicable to its derived versions (e.g. the applicability provisions of Chapter 3 refer to "all … aeroplanes, including their derived versions").

In some cases the applicability provisions apply only to derived versions (e.g. Chapter 8, 8.1.3). In these cases the applicability provisions are determined by the date the application for certification of the change in type design was submitted to the certificating authority of the Contracting State that first certificated the change in type design.

Note.— The applicability provisions for derived versions are not dependent on how the associated change, or changes, in type design came about (e.g. amended Type Certificate or Supplemental Type Certificate).

The authority of the State of Design or, in the case of derived versions, the original certificating authority, should ensure that the demonstration of compliance is in accordance with the procedures and recommended practices that are described in the amendment to Annex 16 that is applicable at the date of submittal for either the Type Certificate or approval of the change in type design as required by Chapter 1, 1.10 through 1.13.

Note.— Changes to test procedures and evaluation methods are usually approved by the Committee on Aviation Environmental Protection (CAEP) on the basis that they are "stringency neutral".

The question arises as to the status of these approvals as each new amendment to the Annex is published.

a) For the authority of the State of Design in the case of new types, or the original certificating authority in the case of derived versions, the approved certification noise levels corresponding to the amendment to the Annex and revision of this manual that were applicable at the time the application for approval was submitted remain valid and should not be reassessed against any changes made in later amendments or revisions.

b) Many applications for a Type Certificate or for approval of a change in type design are submitted to authorities other than that of the State of Design or original certificating authority. Often these applications are submitted several years after their submittal to the first certificating authority. During this period many new amendments to the Annex and corresponding revisions of this manual may have been published. In the case of an application for a Type Certificate or an application for the approval of a change in type design, the applicable Standards are determined according to the provisions of Chapter 1 of the Annex.

For an authority to whom these later submittals are made, the acceptable means of compliance, technical procedures and equivalent procedures would be those described in the amendment to the Annex and the version of this manual that are applicable at the time the applications are submitted to this authority. The applicability provisions of each chapter do not change over time. However the reference and test procedures and the evaluation methods defined in the appendices do, on occasion, change with each new amendment or edition. An applicant may propose, with supporting justification, to the certificating authority to accept the means of compliance and demonstration procedures described in earlier amendments to Annex 16 and equivalent procedures described in earlier versions of this manual on the basis that they are equivalent to the currently applicable ones.

Note.— Bilateral arrangements between Contracting States will facilitate the mutual recognition by other certificating authorities of approvals granted by certificating authorities of the State of Design.

2.2 CHANGES TO AIRCRAFT TYPE DESIGNS INVOLVING "DERIVED VERSIONS"

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

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

2.3 CHANGES TO AIRCRAFT TYPE DESIGNS INVOLVING "NO-ACOUSTICAL CHANGES"

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

a) changes in aeroplane certification noise levels approved by the certificating authority that do not exceed 0.10 dB at any noise measurement point and which an applicant does not track;

b) cumulative changes in aeroplane certification noise levels approved by the certificating authority whose sum is greater than 0.10 dB but not more than 0.30 dB at any noise measurement point and for which an applicant has an approved tracking procedure;

c) for helicopters certificated according to the Standards of Chapter 8 of the Annex, changes in any one of the certification noise levels approved by the certificating authority that do not exceed 0.30 EPNdB; and

d) for helicopters certificated according to the Standards of Chapter 11 of the Annex, changes in the certification noise level approved by the certificating authority that do not exceed 0.30 dB(A).

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

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

b) when the 0.30 dB cumulative change in the aeroplane certification noise level is exceeded, compliance with the Annex requirements is required. The aircraft certification noise levels may not be based upon summation of NAC noise increments;

c) decreases in noise levels 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 (i.e. 0.01 dB). Round-off shall not be considered when judging an NAC (e.g. 0.29 dB = NAC; 0.30 dB = NAC; 0.31 dB = acoustical change); and

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

Due to the applicability dates for Chapters 6 and 10 of the Annex, some light propeller-driven aeroplanes are not required to have certification noise levels. However some modifications to these aircraft can be applied that may impact the noise characteristics. In this case, the NAC criterion application should be treated with a procedure approved by the certificating authority.

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

a) an NAC approval for a derived version shall be made only if the parent “flight datum” helicopter was flight tested to obtain the certification noise levels;

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

c) for changes exceeding 0.30 dB, compliance with the Annex requirements may be achieved either by testing or, subject to approval by the certificating authority, by analytical means. If analytical means are employed, the certification noise levels cannot be used as the “flight datum” for any subsequent design changes.

A flow chart illustrating the criteria for dealing with modified helicopters is presented in Figure 2-1.

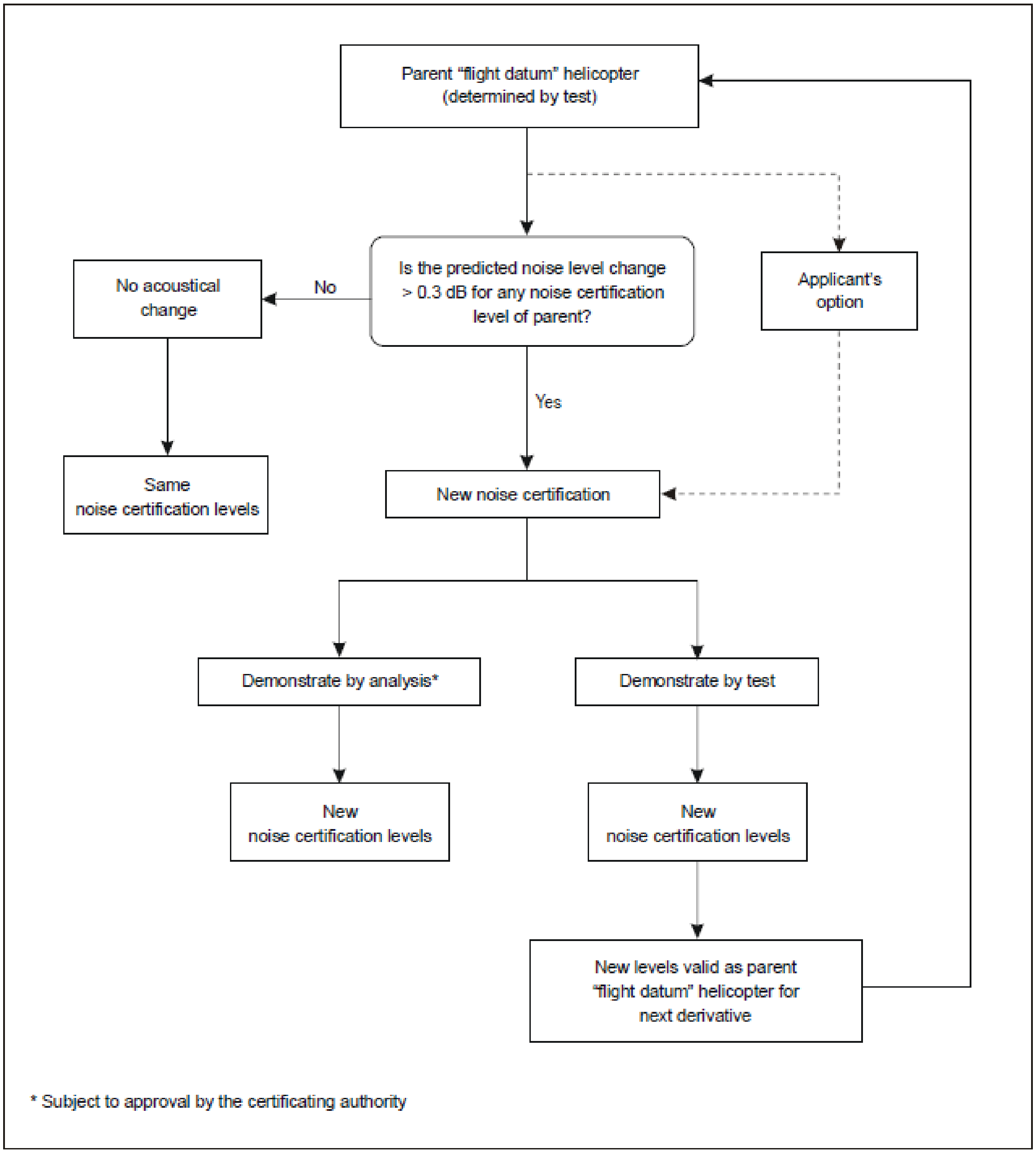

Figure 2-1. "No-acoustical change" criteria for modifications to noise certificated helicopter

Due to the applicability dates for Chapters 8 and 11 of the Annex, some helicopters are not required to have certification noise levels. However some modifications to these helicopters can be applied that may impact the noise characteristics. In this case, the NAC criterion application should be treated with a procedure approved by the certificating authority.

2.3.1 Modifications to helicopters for which changes in noise level(s) need not be determined

Chapters 8 (8.1.5) and 11 (11.1.5) of the Annex require that "certification of helicopters that are capable of carrying external loads or external equipment shall be made without such loads or equipment fitted".

It follows that changes in noise level(s) arising from modifications associated with the installation or removal of external equipment need not be determined. For the purposes of this paragraph "external equipment" means any instrument, mechanism, part, appurtenance, or necessary accessory that is attached to, or extends from, the helicopter exterior but is not used, nor is intended to be used, in operating or controlling the helicopter in flight and is not part of an airframe or engine.

In this respect the following are considered to be no-acoustical changes:

a) the addition or removal of external equipment;

b) changes to the airframe made to accommodate the addition or removal of external equipment, to provide for an external load attaching means, to facilitate the use of external equipment or external loads, or to facilitate the safe operation of the helicopter with external equipment mounted to, or external loads carried by, the helicopter;

c) reconfiguration of the helicopter by the addition or removal of floats and skis;

d) flight with one or more doors and/or windows removed or in an open position; or

e) any changes in the operational limitations placed on the helicopter as a consequence of the addition or removal of external equipment, floats, skis, or flight operations with doors and/or windows removed or in an open position.

2.4 RECERTIFICATION

Recertification 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 certificated".

In the case of an aircraft being recertificated from the Standards of Chapters 3 or 5 of the Annex to Chapter 4, noise recertification 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 recertification basis should be the date of acceptance of the first application for recertification.

The basis upon which the evidence associated with applications for recertification should be assessed is presented in Chapter 9.

2.5 NOISE COMPLIANCE DEMONSTRATION PLANS

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 a complete description of the methodology and procedures by which an applicant proposes to demonstrate compliance with the noise certification Standards specified in the Annex. Approval of the plan and the proposed use of any equivalent procedures or technical procedures not included in the Annex remains with the certificating authority. Noise compliance demonstration plans should include the following types of information:

a) *Introduction.* A description of the aircraft noise certification basis, i.e. the applicable Annex amendment and chapter.

b) *Aircraft description.* Type, model number and the specific configuration to be certificated.

Note.— The certificating authority will normally require that the applicant demonstrates and documents the conformity of the test aircraft and/or engine, particularly with regard to those parts that might affect its noise characteristics.

c) *Aircraft noise certification methodology.* Test concepts, equivalent procedures and technical procedures.

1) For example, the certification of Chapter 3 or 4 aeroplane families (a form of derived versions) often requires approval of equivalent procedures involving measurement and evaluation of static engine noise test data. These procedures include projection of static engine noise test data for development of flyover, lateral and approach noise-power-distance (NPD) plots that define differences between the aeroplane used for the original noise certification flight test and a derived version.

2) Applicants have also proposed taking advantage of programme availability of an aeroplane engine by acquiring static engine noise test data for potential future noise certification applications.

3) Another example of a more general nature involves aircraft type design changes (e.g. mass/thrust, airframe design changes or minor changes in engine components or acoustical treatments), where applicants have proposed using analytical equivalent procedures to derive noise increments to an aircraft's certification noise levels or to demonstrate an NAC between the original certificated aircraft and the derived version.

d) *Plans for tests.* The plans for test should include:

1) *Test description.* Test methods to comply with the test environment Standards and flight path measurement Standards of Appendices 2, 3, 4 or 6 of the Annex, as appropriate, and the applicable take-off and approach reference procedures of the chapters of the Annex appropriate to the aircraft type being certificated.

2) *Measurement system.* Description of measurement system components and procedures including calibration procedures that comply with the Standards of Appendices 2, 3, 4 or 6 of the Annex, as appropriate, and proposed systems and procedures for meteorological and time/space position measurements.

3) *Data evaluation procedures.* Noise evaluation and adjustment procedures, including equivalent and technical procedures provided in this manual, to be used in compliance with the provisions of Appendices 2, 3, 4 or 6 of the Annex, as appropriate to the aircraft type being certificated.

Note.— Plans for tests should either be integrated into the basic noise compliance demonstration plan or submitted separately and referenced in the basic plan.

2.6 NOISE CERTIFICATION REPORTS

After completion of a noise certification demonstration test, an applicant is normally required to submit a noise certification report. This report provides a complete description of the test process and the test results with respect to compliance with the provisions of the Annex noise Standards for the aircraft type being certificated. A noise certification report should include the following types of information:

a) *Basis for test approval.* Identify the approved noise certification compliance plan for the aircraft type and model being certificated.

b) *Description of tests.* Actual configurations tested (aircraft, engines or components), non-conforming items (with justification that they are not acoustically significant or, if significant, can be dealt with by an approved method), test methodology (including equivalent procedures and technical procedures), tests conducted, test data validity, and data analysis and adjustment procedures used.

c) *Test results.* Provide data to demonstrate compliance with the provisions of the Annex regarding maximum noise levels and 90 per cent confidence limits for the aircraft type being certificated.

d) *References.*

Chapter 3

TECHNICAL PROCEDURES APPLICABLE FOR NOISE CERTIFICATION OF ALL AIRCRAFT TYPES

3.1 NOISE MEASUREMENT PROCEDURES

The applicant should submit to the certificating authority for their review and approval technical procedures for the measurement of aircraft noise certification levels. The technical procedures described in the following sections of this chapter should be considered as generally appropriate for all aircraft types. For procedures specific to Appendices 2, 4 and 6 see, respectively, Chapters 4, 5 and 6.

3.1.1 Test site selection

For aeroplanes, when the flight path intercept equivalent test procedure is used, and for helicopters, it may not be necessary for the test site to be located at an airport. Details of the proposed noise certification test-site locations should be submitted to the certificating authority for review and approval. Some test-site criteria that could support selection of a non-airport test site include level terrain, reduced air traffic, reduced ambient noise, improved weather conditions (temperature, humidity and wind), improved microphone placement, availability of field surveys, improved locations for aircraft position monitoring and improved pilot sight and handling.

3.1.1.1 ***Terrain***

Uneven terrain having features such as mounds or furrows can result in reflections that could influence the measured sound levels. Vegetation can reduce the amount of sound that is reflected from the ground surface. In most cases this effect results in a reduced sound level, but under some circumstances the level may be higher. Testing over a smooth hard surface, such as a paved area, will generally result in a higher sound level.

3.1.1.2 ***Grass***

For noise measurement points under the flight path 7.5 m (25 ft) radius circles of mowed grass (not exceeding 8 cm (3 in) height) are acceptable. For noise measurement points located to the side of the flight path, the grass may be mowed in a semicircle of 7.5 m (25 ft) radius facing the line of flight.

3.1.1.3 ***Snow***

Snow in the area surrounding the noise measurement points may provide excessive absorption of aircraft sound reflected from the ground. Noise measurement points have been approved when snow within a 15 m (50 ft) radius of the noise measurement points has been removed. However, snow should not be piled at the borders facing the line of flight.

3.1.1.4 ***Ploughed fields***

Earthen or sandy surfaces within a 7.5 m (25 ft) radius of the noise measurement points shall be reasonably tamped down. Ploughed furrows, silt or soft, powdered surfaces are unacceptable.

3.1.1.5 ***Obstructions***

Obstructions in the vicinity of the noise measurement points such as buildings, walls, trees, vehicles and test personnel, if close enough, may be unacceptable because of reflections that influence measured noise levels. There should be no obstructions that significantly influence the sound field from the aircraft within a conical space above a point on the ground vertically below the microphone at each noise measurement point. The cone is defined by an axis normal to the ground and by a half angle of 80º (75º for light propeller-driven aeroplanes) from the axis as illustrated in Figure 3-1.

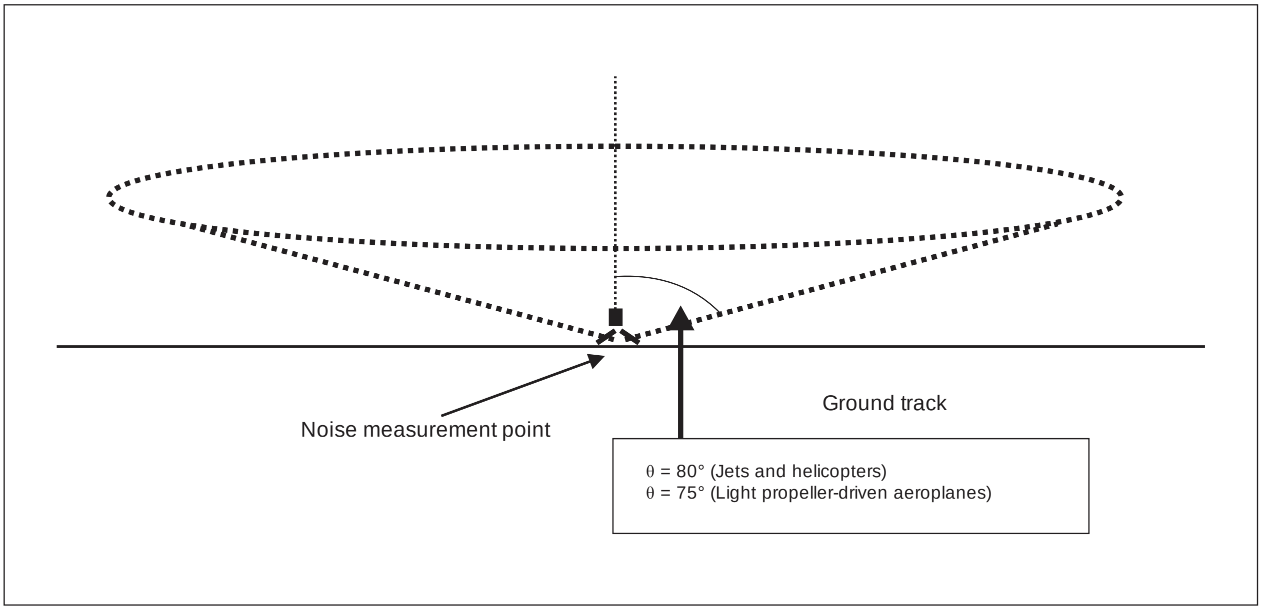

Figure 3-1. Obstruction-free cone defined from the base of the measurements microphone

3.1.1.6 ***Anomalous meteorological conditions***

Certain geographical areas are more susceptible to anomalous meteorological conditions than others (i.e. large variations, or inversions, of temperature or humidity, excessive turbulence or thermally induced vertical winds). The applicant may conduct certification testing only as approved by the certificating authority.

3.1.2 Precautions regarding effects of precipitation

3.1.2.1 ***General precautions***

Fog, rain, drizzle and snow can have a number of adverse effects. Changes in sound generation and propagation under these conditions are not well documented. Most of the equipment used for measuring noise is not intended for use during conditions of precipitation, and the effects can range from changes in microphone and windscreen sensitivity or frequency response, to arcing of conventional condenser microphones, to possible failure of equipment because of electrical short circuits.

3.1.2.2 ***Effects of moisture on microphones***

Most microphones that are used during noise certification testing are susceptible to moisture. Precipitation, including snow, drizzle and fog, or excessive humidity may induce electrical arcing of the microphone sensors, making measured noise data unacceptable. However, some prepolarized microphones are less susceptible to electrical arcing during high-moisture conditions (consult the equipment manufacturer's specifications). Special care should be taken to ensure that any windscreens exposed to precipitation be thoroughly dry, inside and out, before use. Foam windscreens can trap water and wet foam windscreens should be avoided.

3.1.2.3 ***Microphone internal heaters***

When internal heaters are provided, microphones are less likely to be affected by moisture in wet, humid, cold or freezing atmospheric conditions.

3.1.3 Calibration of acoustical measurement system

3.1.3.1 ***General calibration process***

The process for the calibration of an acoustical measurement system (see 3.1 and 3.3.1 of Appendix 2 and 4.2 of Appendices 4 and 6 of the Annex for definition of the "measurement system") for purposes of noise certification testing consists of two parts:

a) Determination of system response corrections; and

b) Sound pressure level calibrations and testing in the field.

Some of these calibrations must be conducted at the aircraft noise test site, with the measurement system configured and deployed for aircraft noise measurement. Note that additional calibrations and checks may be allowed, or required, by the certificating authority.

3.1.3.2 ***Frequency-dependent system response corrections***

Corrections for system response may include consideration of some or all of the following frequency-dependent elements to account for variations in sensitivity differences relative to the calibration check frequency (see 3.9 of Appendix 2 and 4.3 of Appendices 4 and 6 of the Annex).

Note.— To avoid confusion and to promote consistency, it is recommended that all response corrections be determined and presented in such a manner that the correction values are to be added to the measured aircraft noise levels to correctly adjust for the effects of system sensitivity differences. For example, the correction value for a microphone response at a frequency where the microphone is more sensitive to sound than at the calibration check frequency should be presented as a negative number which, when added to the measured aircraft noise levels in that frequency band, lowers them to what would have been measured if the microphone response were flat.

a) *Microphone free-field frequency response*. Corrections for microphone free-field frequency response may be determined using electrostatic actuator testing in combination with manufacturer-provided corrections for free-field conditions, or alternately from anechoic free-field testing using a method approved by the certificating authority (see 3.9.4 of Appendix 2 of the Annex).

b) *Microphone incidence corrections*. Microphone incidence corrections may be required when the microphone is not set at nominally grazing incidence. The corrections may be determined using manufacturer's data, or alternately from anechoic free-field testing using a method approved by the certificating authority (see 3.9.5 of Appendix 2 of the Annex).

c) *Windscreen free-field insertion effects*. The windscreen free-field insertion effects may be determined using manufacturer's data, or alternately from anechoic free-field testing using a method approved by the certificating authority.

Note.— If incidence corrections are required for microphone free-field response, then incidence corrections will likely also be required for the windscreen insertion effects (see 3.9.6 of Appendix 2 of the Annex).

d) *System frequency response*. The frequency response corrections for the measurement system as deployed in the field for aircraft noise measurements (not including the microphone and windscreen, but including any cables, attenuators, gain stages, signal conditioners, etc.) should be determined using a method approved by the certificating authority. Acceptable methods may include the use of discrete or swept sine tones, or random or pseudo-random pink noise. The specific methods and techniques used should be submitted in advance to the certificating authority for approval. When using pink noise to determine system frequency response, there are additional specifications for noise generator performance and calibration specified in the Annex. When using analogue (direct or FM) magnetic tape recording, it is required that system frequency response be determined in the field while deployed for aircraft noise measurements (see 3.8.3 and 3.9.7 of Appendix 2 of the Annex).

e) *Effective bandwidth*. The effective bandwidth (also known as "bandwidth error" or "filter integrated response") for one-third octave band analyser filters may be determined using manufacturer's data, or from tests using discrete or swept sine signals as described in IEC 61260. Note that bandwidth corrections might be redundant, dependent on the specific testing methodology used, if the measurement system response, including the analyser, is determined using pink noise or other broadband signal testing.

3.1.3.3 ***Single-frequency level calibrations***

The following calibrations are typically performed at the calibration check frequency:

a) *Sound calibrator output level*. The output level of the sound calibrator should be determined using means that are traceable to a national standards laboratory. This may include direct calibration by a certified metrology laboratory or comparison calibration methodology. Laboratory calibrations often include a certificate stating the sound pressure level, its tolerance, reference temperature and humidity, and the time period for which the calibration remains valid. This and other documentation may be required by the certificating authority for their approval. Sound calibrator output level corrections for barometric pressure, coupler volume, and other environmental effects may be determined according to the manufacturer's specifications.

b) *Calibration of gain or attenuation settings*. The accuracy of gain or attenuation settings (range changes) for switchable components in signal conditioners, amplifiers, analysers and sound level meters should be determined from manufacturer's specifications or by laboratory testing, as approved by the certificating authority.

c) *Sound pressure level sensitivity of the acoustical measurement system*. Sensitivity calibrations of the entire system must be performed before and after each day's aircraft noise measurements using an approved sound calibrator. These calibrations should be performed in such a way that all system components, including cables, are accounted for.

3.1.3.4 ***Field sound pressure level calibration considerations***

It is necessary to establish and monitor the overall sound pressure level sensitivity of the measurement system while it is deployed in the field. Considerations for such field sound pressure level calibrations include:

a) *Schedule for sound pressure level calibrations*. For aircraft noise certification tests defined in Appendices 2, 4 and 6, an acoustic calibration signal of known amplitude and frequency should be applied to the entire measurement system, including the microphone, while deployed in the field. This calibration should be performed as a minimum at the start and end of each day of aircraft noise measurements. When analogue (direct or FM) magnetic recording media are used, the signal from the sound calibrator should also be recorded at the beginning of each physical volume of recording media (e.g. each tape reel, cartridge, or cassette) as well as at the end of the last physical volume of recording media. In addition, sound pressure level calibrations should be considered at regular intervals throughout each day of aircraft noise measurements (see 3.9.2 and 3.9.3 of Appendix 2; 4.3.4 of Appendix 4; and 4.3.3 of Appendix 6 of the Annex). As an example, sound pressure level calibrations are sometimes scheduled to coincide with meteorological flights between noise measurement runs, or during test aircraft refuelling for longer test programmes. Applicants should include the scheduling of such calibrations in the noise measurement test plan;

b) *Aircraft noise data validity*. Aircraft noise data that are not preceded and succeeded by valid sound pressure level calibrations are not acceptable for aircraft noise certification purposes. The Annex specifies that the difference between pre- and post-calibrations must not be greater than 0.5 dB. Because of this limitation, frequent checks of system sensitivity and functionality are advised (see 3.9.2 of Appendix 2; 4.3.4 of Appendix 4; and 4.3.3 of Appendix 6 of the Annex);

c) *Insert "checks"*. Depending upon the specific measurement system configuration, and with the approval of the certificating authority, level sensitivity checks (e.g. charge or voltage "insert" calibrations, which involve electrical signals injected into the microphone preamplifier) at frequent intervals (e.g. every two hours of aircraft noise measurement deployment) may be used to supplement the requirement for sound pressure level calibrations at the start and end of each day of aircraft noise measurement. Employing such a procedure can facilitate continuous testing activity, and provide supporting data to isolate and identify potential system failures. Insert checks should not be considered as substitutes for required sound pressure level calibrations;

d) *System configuration during sound pressure level calibrations in the field*. During field sound pressure level calibration, all components of the measurement system including cables, attenuators, gain and signal-conditioning amplifiers, filters (including pre-emphasis, if used) and power supplies, but excluding the windscreen, should be in place. Where used, attenuators and gain stages should be set to prevent overload and to maintain the calibration signal level within the reference level range specified in 3.6.6 of Appendix 2 of the Annex. If any switchable filters that could affect the calibration signal are utilized during measurements, then sound pressure level calibrations should be performed both with and without these filters enabled. Components of the electrical system should not be added, removed or replaced without re-calibrating any part of the system affected by that component immediately before and after making each change; and

e) *Adjustments for differences between pre- and post-calibrations*. Section 3.9.2 of Appendix 2 of the Annex requires that the arithmetic mean of the sound pressure level calibrations before and after a group of aircraft noise measurements shall be used to represent the acoustical sensitivity level of the measurement system for those measurements. No such requirement is provided for in Appendices 4 or 6 of the Annex. Nevertheless the certificating authority may approve such an adjustment to the system's acoustical sensitivity level. In all cases, and as an alternative to the arithmetic mean of the before and after sound pressure level calibrations, the certificating authority may accept that for a particular aircraft noise event the acoustical sensitivity level of the system be represented by a linear interpolation over time of the sound pressure level calibrations before and after the aircraft noise measurement to the time of the data acquisition for that aircraft event.

3.1.3.5 ***Application of calibration corrections***

It is recommended that all calibration corrections should be determined and presented in a manner such that they are to be **added** to the measured aircraft levels to properly correct for system instrumentation effects (see Note to 3.1.3.2).

All calibration corrections should be determined individually, reported with full documentation of the method of determination, and applied to the measured aircraft noise levels during data processing of analysed one-third octave band sound pressure levels. This includes sound calibrator output adjustments for ambient conditions such as temperature and atmospheric pressure, coupler volume (see 3.8.2 of Appendix 2 of the Annex), as well as any sensitivity "drift" corrections or any system response corrections.

Note 1.— Such adjustments should not be applied by adjusting the calibration value in the analyser or sound level meter.

Note 2.— In the event that the sound pressure level sensitivity of the analyser or sound level meter needs to be reset after the initial calibration at the start of the test day, and after aircraft noise measurements have already been obtained, then prior to such reset, the sound pressure level calibration signal should be measured and recorded at the existing level sensitivity. In this way, a traceable record of the system sensitivity can be maintained.

3.1.3.6 ***Calibration traceability***

All sound calibrator output levels and performance testing of calibration instrumentation should be traceable to a national standards laboratory. The method of traceability may in some cases include documentation of any comparison calibration methods performed by the applicant, instrumentation manufacturer or another third party. All methods of traceability must be approved by the certificating authority.

3.1.4 Windscreen insertion loss

The physical condition of a windscreen can significantly affect its performance due to insertion loss. Only new or clean dry windscreens should be used.

Insertion loss data adjustments for windscreens used during aircraft noise evaluations under the provisions of Appendix 2 of the Annex may be obtained from manufacturer's data or by free-field calibration in an anechoic chamber (see AMC A2 3.9.6).

For aircraft noise evaluations made under the provisions of Appendices 4 and 6 of the Annex, windscreen insertion loss data adjustments may be required.

3.1.5 Wind speed limitations

The wind speed should be monitored against the specified wind speed limits. In cases where these limits are exceeded during an aircraft test run, that test run is invalid and might have to be repeated. No method has been approved for making data adjustments for wind speed or direction.

3.1.6 Measurement of meteorological conditions

The temperature and relative humidity near the earth's surface can be affected by numerous factors including solar heating, surface winds, local heating or cooling, increased or decreased local humidity, etc. To avoid localized anomalous conditions that often occur near the ground, meteorological measurements are to be made 10 m (33 ft) above the surface for aircraft noise measurements made under the provisions of Appendix 2 of the Annex and between 1.2 m (4 ft) and 10 m (33 ft) for aircraft noise measurements made under the provisions of Appendices 4 and 6 of the Annex. The meteorological conditions measured above the ground are assumed to be constant from the ground surface to the height at which they are measured.

Meteorological specifications for tests conducted according to Appendices 2, 4 and 6 are defined in 2.2.2.1 of Appendix 2 of the Annex. Atmospheric conditions shall be measured within 2 000 m (6 562 ft) of the microphone locations and shall be representative of the conditions existing over the geographical area in which noise measurements are conducted.

If an applicant can show that measurements from a fixed meteorological station, such as might be found at a nearby airport comply with these requirements, then subject to the approval of the certificating authority, this facility may be used. Approval will normally require the applicant to show that the measurement systems have been calibrated within 90 days prior to the tests.

In general, an approved portable system is preferred. This will be especially important when any of the meteorological conditions, in particular wind speed, are near their limits. Applicants should note that in order to determine the crosswind component, an accurate measure of not only wind speed but also wind direction is required. Some wind direction indicators installed at airfields and airports have a slow response to rapid changes in wind direction and are not sufficiently accurate.

3.1.7 The ICAO Standard Atmosphere

Throughout the Annex there are references to the ICAO Standard Atmosphere, details of which can be found in ICAO Doc 7488/3. Many of the chapters in the Annex define the reference atmospheric conditions with references to temperature and pressure lapse rates.

In such cases the temperature can be assumed to decrease with altitude at a constant rate of 0.65˚C per 100 m.

However the rate of change of reference atmospheric pressure varies with altitude. The reference pressure at a given altitude is defined by the following equation:

$$p_R = 1013.25 \times \left(1 - 0.0065 \times \frac{H_R}{288.15}\right)^{\frac{-9.80665}{-0.0065 \times 287.05287}}$$

3.1.8 Aircraft position measurement

Appendices 2, 4 and 6 specify that the aircraft position shall be determined by a method independent of normal flight instrumentation. For this purpose certificating authorities have approved differential global positioning systems (DGPS), radar tracking, theodolite triangulation or photographic scaling techniques (see 3.2).

3.1.9 Measurement system specifications

3.1.9.1 ***Validation of measurement system configuration***

Each applicant should submit information to the certificating authority about the measurement system used. The certificating authority will determine whether any listed components require approval.

3.1.9.2 ***Changes in measurement system configuration***

If an applicant makes changes to the approved measurement system configuration, the certificating authority should be notified before aircraft noise certification testing to determine whether additional evaluation and approval are required.

3.1.10 Noise compliance demonstration plan

An applicant should prepare a noise compliance demonstration plan (see 2.5), that specifies the proposed certification process, including the use of any equivalencies. This plan is to be submitted to the appropriate certificating authority allowing sufficient time to permit adequate review and possible revisions prior to the start of any noise certification testing.

3.2 AIRCRAFT POSITION AND FLIGHT PATH MEASUREMENT

Appendices 2, 3, 4 and 6 of the Annex specify that the aircraft position shall be determined by a method independent of normal flight instrumentation. Approved examples of methods used for the measurement of aircraft height and lateral position relative to the intended flight path, as a function of time, include:

a) differential global navigation satellite system (DGNSS)-based tracking systems; and

b) photographic scaling.

Practical examples of aircraft tracking systems employing these techniques are described in the following sections. Other methods may be used if the system can be demonstrated to provide similar accuracy at an adequate sample rate. Tracking systems such as radar tracking, theodolite triangulation, inertial navigation systems (INS), and microwave systems, which have demonstrated a high degree of accuracy, have been accepted in the past by several certificating authorities for use during noise certification.

3.2.1 DGNSS-based time-space-position information tracking system

3.2.1.1 General

Global navigation satellite system (GNSS) receivers are widely available to obtain time-space-position information (TSPI) for general use. These receivers utilize signals from established satellite networks such as the US NAVSTAR global positioning system (GPS), the Russian global navigation satellite system (GLONASS), and the EU Galileo system. However, conventional GNSS receivers on-board aircraft are not considered to be sufficiently accurate to obtain TSPI for noise certification testing.

A significant improvement in accuracy can be achieved by supplementing the GNSS data obtained on-board the aircraft with data from a second local fixed-position GNSS receiver at a known location. Such an arrangement is the most accurate version of a category of correction methods referred to as differential GNSS (DGNSS).

The approval of DGNSS systems by certificating authorities is based on the characteristics of the hardware, related software, installation and operational procedures proposed by the applicant. It is recommended that the requirements described in this section be used to assess the acceptability of DGNSS systems proposed for use during noise certification testing.

Typically the hardware consists of GNSS receivers and antennas located on the ground and in the aircraft, a data link between the ground and the aircraft, along with related personal computers and power supplies (see Figure 3-2). The computer on-board the aircraft provides the user with control/display functions and performs data logging. The ground-based computer is generally needed to initialize the GNSS receiver on the ground, but is typically not necessary for continuous operation.

In addition to generating TSPI data for noise data processing, some systems also provide the pilot with information to more precisely fly the aircraft according to the target procedures. The actual aircraft position is compared to the target reference flight path. Steering instructions are sent to a course/glide slope deviation indicator (CDI/GDI) installed specifically for use with the DGNSS system.

Variations on the basic architecture shown in Figure 3-2 are possible. For example the data link elements may be eliminated by collecting and storing data from both DGNSS receivers and post-processing these data after the flight is completed. However without a data link DGNSS data cannot be used for aircraft guidance, nor can an aircraft-based operator obtain “quick-look” information regarding the quality of the DGNSS solution. Another possible variation involves the use of a two-way data link. Typically, identical radio transceivers would be used on the ground and in the aircraft to transmit TSPI data to a ground station. This enables ground tracking of the aircraft during testing.

To date the DGNSS systems approved by certificating authorities for noise certification testing have been based on differential GPS (DGPS). Sections 3.2.1.2 and 3.2.1.3 discuss TSPI acquisition using GPS and describe criteria developed for DGPS implementation on noise certification tests. Specific criteria for other DGNSS systems have not yet been developed.

Note that satellite-based augmentation systems (SBAS) such as WAAS and EGNOS may be acceptable in the future subject to criteria under development. Commercially available SBAS services that provide a dual-frequency L1/L2 correction solution, such as the OmniSTAR XP service, have been accepted by some certificating authorities due to their position accuracy being comparable to DGPS.

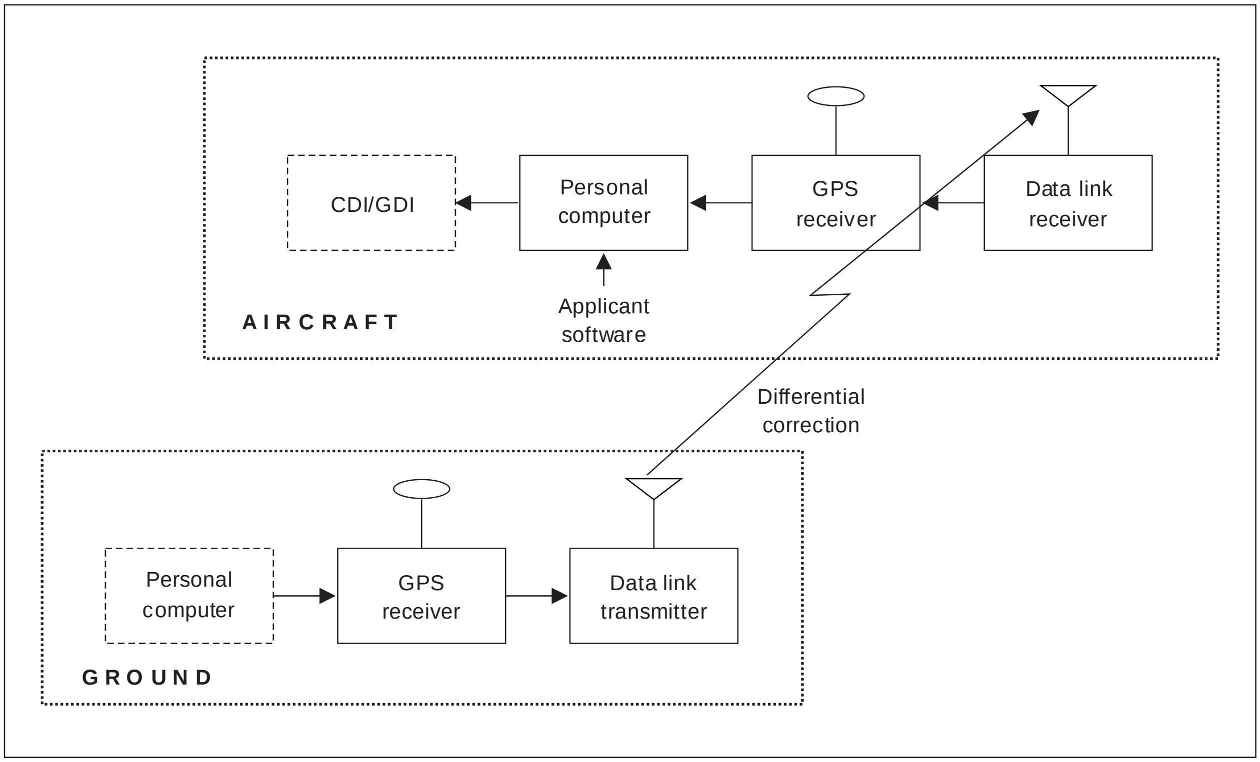

Figure 3-2. DGNSS TSPI system basic architecture

3.2.1.2 DGPS implementation considerations

This section discusses considerations for DGPS implementation, including design issues, system configuration, test site survey, DGPS receiver output data, and possible sources of error.
3.2.1.2.1 Coordinate frames and waypoint navigation

The native coordinate system for GPS (i.e. the one in which its computations are performed) is the World Geodetic Survey of 1984 (WGS-84). Most GPS receivers also provide output position information (latitude, longitude and height) in a variety of geodetic coordinate systems by transforming the WGS-84 position data.

Aircraft noise certification tests typically involve the use of a local rectangular coordinate frame whose definition is based upon the array of microphones or the centre line of an airport runway. Typically the frame's x-axis is established from two points on the ground that are nominally aligned with the runway centre line; the y-axis is orthogonal in the horizontal plane to the x-axis, and the z-axis is perpendicular to the horizontal plane. The geodetic position solution (i.e. latitude, longitude and height) must be transformed to the local coordinate system through post-processing prior to noise data processing.

Some GPS receivers can furnish data in a rectangular coordinate system based on waypoints. These are user-defined reference points intended to facilitate navigation along a route or in a local area. The initial survey performed to determine the position of the waypoints is critical to the accuracy of the TSPI results (see 3.2.1.2.2). If a receiver supports waypoint navigation then two such points, defined in terms of latitude, longitude and altitude, can be entered into the receiver. The receiver will subsequently provide the aircraft position relative to the coordinate frame implicitly defined by these points (i.e. the distance from the line connecting the two points and the distance to one point). For noise certification testing it is recommended that the GPS receiver reads the waypoints from a printable data file. Alternatively, the waypoints may be keyed into the receiver and written to a data file.

3.2.1.2.2 Test site survey

A careful survey of the test arena where noise testing is to be conducted is critical to the success of a measurement programme. The following steps are involved in the survey:

a) An initial reference location is selected. Its coordinates, including numerical values for its latitude, longitude and elevation, are stored in a permanent file for record keeping. Normally the initial reference location will be a surveyed monument of known latitude and longitude. The location of the monument will often have been derived from a third-order survey, in which case geodetic position errors of the order of hundreds of metres are not uncommon. However such errors have no effect on the measurement of positions relative to that point or another point derived from it. The elevation of the monument can be assumed to be the published airport reference elevation. This elevation is typically applicable to the base of the tower. The height difference between the monument and tower may be ignored. This will not degrade the accuracy of any differential measurements that are made relative to the reference location.

   Note.— Alternatively many GPS receivers have a "survey" mode to generate a surveyed position, whereby the receiver averages position measurements over a user-selected period (e.g. 8 to 24 hours). The resulting absolute accuracies, typically less than 3 m (10 ft), are sufficiently accurate if the DGPS-based TSPI system measurements are not to be related to measurements from another system.

b) The ground-station antenna may be installed at the initial reference location for the duration of the test series. Otherwise, a new reference location must be established where the ground station antenna will be installed for the remainder of the test series. This is accomplished using the roving GPS receiver and antenna used for the site survey, with the ground-station antenna installed at the initial reference location. The latitude, longitude and elevation of this new (normal) location is stored in a permanent file for record keeping.

c) If waypoint navigation is to be used the DGPS-based TSPI system, with the ground station at its normal location, is used to measure the latitude, longitude and elevation of the FROM and TO waypoints to be used to establish the test programme coordinate frame. At least three measurements should be made to minimise errors. The resulting locations should be stored in a permanent file for record keeping.

d) The DGPS-based TSPI system, with the ground station at its normal location, is used to measure latitude, longitude and elevation of each microphone position and converted to test coordinates. The measured positions are stored in a permanent file for record keeping. If waypoint navigation is to be used then the microphone positions should be recorded in test coordinates.

e) If it is not feasible to use the DGPS-based TSPI system to survey all of the microphone locations, then direct measurements of at least three common points should be performed in order to determine the relationship between the two surveys. For example, if the microphones are surveyed using classical techniques, then a DGPS-based TSPI survey of the two microphones at the ends of a microphone line and one other microphone, as far removed from the first two as possible, will be sufficient. The results of the two surveys should agree to within 30 cm (1 ft) at each common point. If they differ by more than 30 cm (1 ft) and the difference can be expressed in terms of an offset and a rotation, then the results of one survey should be adjusted to agree with the other. Such adjustments should be approved by the certificating authority prior to testing.

The test site survey should be performed before and after each measurement programme. Post-test data reporting should include a comparison of the two surveys.

3.2.1.2.3 Receiver output data

This section addresses the GPS receiver output data (receiver messages[1]) that are of interest.
Three kinds of GPS receiver output data are of interest:

a) TSPI data stored during flight testing for use during post-test processing of noise data, as collected either from the aircraft receiver when a real-time data link is used, or from both receivers when a real-time data link is not used;

b) differential correction data output by the ground-station receiver, transmitted to the aircraft via a real-time data link, and input to the aircraft receiver. These data may not be stored, but directly influence the accuracy of the TSPI data stored during flight testing (3.2.1.2.3a); and

c) data collected from the ground-station GPS receiver during multi-path verification tests prior to flight testing (see 3.2.1.2.6).

3.2.1.2.3.1 Data stored during aircraft noise testing when a real-time data link is used

GPS receivers provide TSPI data in a variety of formats, both industry-standard and proprietary. In the United States, the National Marine Electronics Association (NMEA) has issued standards (Reference 8) that are intended to facilitate user communications with GPS receivers and other navigation devices. Some GPS manufacturers have adopted NMEA standards, some use proprietary formats, and some use both.

Different GPS receivers often use different parameters to indicate the quality or status of the TSPI data. Receivers typically calculate a position dilution of precision (PDOP) value, where a value of 4 or less indicates a satellite geometry (for those in view) that is sufficient for the precise calculation of a position solution. DGPS-based TSPI systems using a real-time data link should save the unprocessed aircraft GPS receiver output data in permanent files. Stored data should include time (e.g. UTC or GPS time with or without the local offset), aircraft latitude, longitude and height (or aircraft position relative to a pre-defined waypoint), together with a status or quality flag indicating the reliability of the DGPS solution.

Typically the applicant should employ software to read the unprocessed data, analyse and format these data, perform any necessary coordinate transformations, and generate a file to be used for noise data processing. Storage of the unprocessed data allows the certificating authority to verify the validity of the processed results.

3.2.1.2.3.2 Data stored during aircraft noise testing when a real-time data link is not used

DGPS-based TSPI systems considered for noise certification tests that do not use a real-time data link should save data from both the ground and aircraft GPS receivers in raw (i.e. the receiver's native) format in permanent files. Manufacturers' proprietary formats should be used because NMEA standard messages do not support this application.
For post-processing, stored data should include:

a) time (e.g. UTC or GPS time) with or without the local offset;

b) satellite ephemeris (see 3.2.1.2.6.4 for a discussion of satellite ephemeris/clock data);

c) pseudo-ranges, the receiver's measured distance to a satellite derived from the L1 Coarse/Acquisition (C/A) code, including the receiver clock bias error quantified in units of time or distance;

1. Standards organizations and manufacturers employ different terminology for pre-defined groups of data parameters available from receiver output ports. For example, in the United States, the National Marine Electronics Association (NMEA) uses the term "sentences," the Radio Technical Commission for Maritime Services (RTCM) uses "messages," Novatel Communications uses "logs" and Trimble Navigation Ltd. uses "cycle printouts."

d) signal-to-noise ratios, also called carrier-to-noise ratio, derived from the receiver's tracking loop circuits. The signal-to-noise ratio is a measure of the received signal strength, and is usually quantified in dB Hz and varies from approximately 33 to 50;

e) carrier phase, the amount of L1 carrier cycles that have accumulated since logging of this parameter was begun; and

f) for applicants using dual-frequency (L1/L2) receivers, the L2 carrier phase data.

Note.— The highest accuracy DGPS systems employ the L2 signal carrier as the basic correction parameter. These techniques require that the number of full carrier cycles between the ground station and aircraft be determined once during a test. After the cycle count is established, the ground-station/aircraft separation is tracked to fractions of a wavelength, provided that the receiver carrier tracking loops (circuits) maintain phase lock.

Typically, post-processing of the ground-based and airborne GPS data will be performed using manufacturer-supplied or other commercial software. If this is not the case, then any software developed by applicant should be approved by the certificating authority.

3.2.1.2.3.3 Real-time DGPS messages

GPS receiver manufacturers have implemented both industry-standard and proprietary messages for use on real-time DGPS data links. Most manufacturers follow a standard (Reference 10) issued by the Radio Technical Commission for Maritime Services (RTCM), Special Committee 104 (SC-104). Some manufacturers have also implemented proprietary DGPS messages that frequently are similar to the RTCM/SC-104 messages.

For applicants implementing a real-time DGPS data link, it is preferred that RTCM/SC-104 messages be employed. Type-1 or Type-9 messages, each of which contains the actual DGPS corrections, should be selected and transmitted at a rate of 0.5 Hz or higher. Other message types (e.g. Type-3 ground-station location and Type-5 satellite health) may also be used, and sent at a rate of not more than once per minute. There is no recommended requirement for storing real-time DGPS correction data. The data status or quality flag (see 3.2.1.2.3.1) provides an indication that the correction data have been properly received and processed by the aircraft.

3.2.1.2.4 Messages for multi-path testing

Applicant-designed systems using code-based DGPS processing should collect and save data from dedicated multi-path tests. These tests should be conducted prior to aircraft noise testing (see 3.2.1.2.5). Data collected during multi-path tests should include individual satellite pseudo-ranges and signal-to-noise ratios. These parameters are provided only by receiver manufacturers' proprietary messages. It is not necessary for applicants to conduct a dedicated multi-path test for systems using carrier-based DGPS processing.

3.2.1.2.5 System accuracy and sources of DGPS error

A change of approximately 1.1 per cent of the distance between the aircraft noise source and the microphone corresponds to a 0.1 dB change in the noise level (taking into account only spherical spreading and not atmospheric absorption). Thus for an aircraft height of 122 m (400 ft) above the microphone array, the approximate minimum height flown during noise certification tests, a position error resulting in a 1.3 m (4.3 ft) error in the sound propagation path length from the aircraft to the microphone can be expected to introduce a 0.1 dB error in the processed noise data. An error of 3.0 m (9.8 ft) in the sound propagation path length can be expected to introduce a 0.23 dB error in the processed noise data.

For most DGPS systems the most significant sources of error are, in decreasing order of importance, multi-path, correction latency and tropospheric delay. When these error sources are properly controlled DGPS systems can provide accuracies between a few centimetres and approximately 5 m (16 ft) for an aircraft in low speed, stable flight. Even the worst of these accuracies is superior to that achieved by other TSPI systems historically used for aircraft noise tests such as microwave and photo-scaling. The best accuracies are superior to those of laser tracking.

DGPS systems suitable for noise certification purposes should achieve an accuracy of between a few centimetres to 1.5 m. The highest accuracy is achieved using carrier-based techniques and post-flight processing of data collected from both the aircraft and ground-station. Code-based solutions that use carrier smoothing achieve accuracies of 0.9 m to 1.5 m (3.0 ft to 4.9 ft), provided that the error sources discussed in this section are properly addressed. Consequently it is expected that in a worst-case scenario (i.e. a noise certification approach measurement) the DGPS systems used for noise certification tests will introduce less than a 0.2 dB error into the noise data. Errors for noise certification flyover and lateral measurements will typically be less than 0.1 dB.

Note.— In addition to the three error sources cited above, increases in DGPS position errors can also occur when the model of the ground station and aircraft GPS receivers are not the same, or when the ground station and aircraft receivers use different satellite ephemeris/clock data to specify the satellite orbital parameters.

Sections 3.2.1.2.6 and 3.2.1.2.7 address all of the above errors and include methods for minimizing these errors or eliminating them entirely.

3.2.1.2.6 Multi-path errors

3.2.1.2.6.1 Characteristics

Multi-path refers to signals from GPS satellites that are reflected from objects (e.g. the ground, buildings and aircraft structural elements) before reaching the GPS antenna. Multi-path signals add algebraically to the desired line-of-sight signal and thereby decrease the accuracy of measurements made with the line-of-sight signal. Multi-path conditions can occur at both the aircraft and ground station antennas. Thus the differential correction data from the ground are not useful for correction for multi-path errors at the aircraft antenna. Rather, the broadcast corrections can contain ground-station multi-path errors which, in a statistical sense, add to the errors seen at the aircraft.

Measurements have consistently shown that the presence of multi-path conditions at the ground station is significantly more harmful than at the aircraft. This is because ground-station multi-path conditions vary slowly, acting like a bias over the duration of a test run, whereas the more dynamic motion of the aircraft causes the effects of airborne multi-path conditions to behave like noise, which can be reduced somewhat by processing techniques such as filtering and averaging.

The extent of the multi-path error primarily depends on two factors: the capability of the ground station antenna and the location of the ground station antenna relative to reflecting objects such as paved runways, buildings and parked aircraft. Receiver processing and/or carrier smoothing, available from several manufacturers, can reduce multi-path errors.

For code-based processing, ground station multi-path error is typically between 0.3 m and 3 m (1.0 ft and 9.8 ft). Under very adverse conditions (e.g. a GPS antenna near the side of and at the base of a large building) multi-path errors can be up to 150 m. Multi-path errors associated with carrier-based processing techniques are significantly less than those for code-based methods. They are usually of the order of centimetres and can therefore be ignored.

3.2.1.2.6.2 Code-based system ground station

To mitigate the effects of multi-path conditions on DGPS-based TSPI performance, the applicant's ground station installation should meet the following requirements:

a) the ground station should employ a multi-path-limiting antenna, such as one with a choke ring or an absorbing ground plane; and

b) the ground station antenna should be mounted on a pole or tower, with unobstructed visibility of the sky. A minimum height of 1.82 m (6 ft) above ground level is recommended for the ground-station antenna.

Additionally, to ensure that significant undetected multi-path errors do not corrupt the TSPI data collected during aircraft noise testing, the applicant's ground-station installation should be tested for adequate performance under multi-path conditions prior to commencing the flight test. This can be done by collecting GPS receiver data during the same hours of the day that the system will be used for noise tests, with additional one-hour buffers on either side of this period. The data are then examined on a per-satellite basis, rather than navigation solution basis, for multi-path signatures. This examination should include pseudo-ranges and signal-to-noise ratios. Reference 1 (beginning on page 560) gives a procedure for examining GPS data for multi-path.

If multiple periods of significant multi-path errors (i.e. several metres) are found, then a new location for the ground-station antenna should be selected and tested. If only one or two isolated, brief multi-path incidents are found, then the antenna location can be retained but aircraft testing should not be conducted during these periods.

Note.— The satellite-user geometry repeats over a cycle of approximately 23 hours 56 minutes. Thus if a ground station multi-path incident is observed one day, it is expected that a similar incident will occur 4 minutes earlier the following day.

After establishing a ground-station antenna site/configuration that satisfies the multi-path conditions criterion, the ground-station antenna should not be moved without performing another multi-path test. The ground-station GPS receiver and any computer used in conjunction with the receiver may be removed and reinstalled without repeating the multi-path test. The multi-path verification test data should be saved as part of the permanent test-series data archive and should be made available for inspection by the certificating authority.

3.2.1.2.6.3 Carrier-based system ground station

To mitigate the effects of multi-path conditions on DGPS-based TSPI performance, the applicant's ground-station installation should meet the following recommended specifications:

a) the ground station should employ a multi-path-limiting antenna, such as one with a choke ring or an absorbing ground plane; and

b) the ground station antenna should be mounted on a pole or tower, with unobstructed visibility of the sky. A minimum height of 1.82 m (6 ft) above ground level is recommended for the ground-station antenna.

There is no recommended requirement for collecting data to assess multi-path errors when carrier-based processing is employed.

3.2.1.2.6.4 Aircraft installation

For noise certification flight tests GPS antennas should be located on the test aircraft such that multi-path effects are minimised. In this regard no recommended specifications have been developed. For most smaller aircraft (e.g. 10 seats or fewer), it has been found that the roof area directly behind the windshield is most advantageous. Manufacturers of larger aircraft have found forward positions on the roof to be desirable, although some have mounted the GPS antenna on the tail structure. Selecting a location for the GPS antenna on a helicopter may be more challenging since the main rotor will momentarily obscure most areas on the airframe.

3.2.1.2.7 Other sources of DGPS error

3.2.1.2.7.1 Correction latency

Correction latency, or staleness, refers to the delay between the time of validity of a differential correction at the ground station and the time that the correction is applied in the aircraft. Delays in processing at both ends of the ground-to-air data link can cause stale corrections to introduce unacceptably large errors.

For a system with a real-time data link that employs code-based DGPS solutions, it is strongly recommended that ground-to-aircraft messages conform to the RTCM/SC-104 standards used by the US Coast Guard DGPS system.[2] These messages contain pseudo-range rates-of-change, as well as the correction at an identified time, to allow the user to correct for most of the latency-induced error. Corrections should be computed and transmitted at least at a 0.5 Hz rate.

A second form of latency, solution latency, refers to the delay between the time at which a GPS receiver's measurement is valid and the time when it is available at the output of the receiver. Solution delays are inherently smaller than correction delays and, for noise certification purposes, are of concern only for aircraft guidance.

A third form of latency could occur if the GPS receiver output is merged into an aircraft instrumentation data stream for storage. Care should be taken that the GPS data time stamp is preserved and aligned correctly with the recording system time.

3.2.1.2.7.2 Tropospheric delay

The troposphere is that portion of the atmosphere between the earth's surface and an altitude of approximately 32 km (20 miles). Differences in meteorological conditions between the ground station and the aircraft can cause dissimilar changes in the propagation times of signals from a satellite to these two locations. The effect is most pronounced for low-elevation-angle satellites and equipment manufacturers recommend using only satellites that are at least 5 to 10 degrees above the horizon. Since these changes are not common to the two locations, they are not removed by differential corrections. Such tropospheric effects can contribute up to 20 m (66 ft) of ranging error on GPS signals, which can translate into as much as 10 m to 12 m (33 ft to 39 ft) of positioning error if not modelled and corrected. In differential mode this positioning error is typically less than 2 m (6.6 ft). Approximately 90 per cent of these tropospheric propagation-related errors are due to the hydrostatic, or dry, component of tropospheric delay.

To reduce the effects of tropospheric errors on DGPS-based TSPI systems, it is recommended that use of these systems be limited to the aircraft being within a lateral distance of 37 km (23 miles) and a height of 1 524 m (5 000 ft) relative to the ground station.

If desired, the hydrostatic component of the tropospheric delay can be effectively removed with the tropospheric delay model (Reference 9) developed by the Radio Technical Commission for Aeronautics (RTCA) as per ICAO Annex 10 Standards and Recommended Practices (SARPs), along with local meteorological measurements at the ground station. The relevant portion of this model is driven by local barometric pressure and satellite geometry (i.e. elevation angle). Reference 18 provides a functional overview of the RTCA model, as well as comparisons with other tropospheric propagation delay models.

3.2.1.2.7.3 Mismatched GPS receivers

Experiments have shown that DGPS errors are increased when the GPS receivers at the ground station and in the aircraft are not "matched" in terms of manufacturer and model. With mismatched receivers, errors are increased between 1.5 to 3 times compared to those when the receivers are matched and when the satellites are operating normally. Applicants' systems should use the same manufacturer/model GPS receiver on the ground and in the aircraft.

3.2.1.2.7.4 Mismatched satellite ephemeris/clock data

GPS satellite broadcasts include a navigation message in the form of 50 bits per second modulation superimposed on the pseudo-random codes used for ranging. Within the navigation message are data sets that describe the satellite orbit (i.e. ephemeris information) and clock. These data sets are transmitted every 30 seconds. The NAVSTAR GPS Control Segment uploads multiple ephemeris and clock data sets to the satellites, typically once per day.

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2. The United States Coast Guard DGPS system's broadcast messages (as well as marine systems of other nations) include the rate-of-change of each pseudo-range error, in addition to the pseudo-range error at a reference time. The user's receiver is required to apply an adjusted correction consisting of the broadcast pseudo-range error, plus its rate-of-change multiplied by the time elapsed between the time the adjusted correction is applied, and the validity time for the pseudo-range correction.

Satellites typically change their broadcast ephemeris and clock message every four hours. The ephemeris/clock data sets are used by a receiver to compute its own position and, in the case of a reference station, differential corrections for use by other receivers. For a DGPS system to achieve full accuracy, both the ground station and aircraft receiver must use the same ephemeris and clock data sets. Internal receiver logic ensures that the ephemeris and clock data sets used by a given receiver are consistent for each satellite. However, occasionally the ground and aircraft receivers may use different ephemeris/clock data sets unless measures are taken by the user to ensure that the sets match. Mismatched ephemeris/clock data sets can occur for several reasons. A receiver might be too busy performing other tasks when the data sets change, or a receiver encounters an error while decoding new data and continues to use an old data set.

RTCM/SC-104 messages guard against mismatched ephemeris/clock data sets by including the issue of data (IOD), an eight-bit data set label broadcast by each satellite, in the broadcast messages (References 10 and 19). User receivers that conform to the RTCM/SC-104 standards will not apply differential corrections unless the IOD from the satellite and the DGPS correction message agree. The applicant should ensure that during testing the ground station and aircraft use the same ephemeris and clock data sets. One way is to use GPS receivers and select DGPS messages that cause this check to be performed automatically. Another way to ensure agreement between the ground and aircraft ephemeris/clock data sets is to store in a permanent file, at a rate of once every 30 seconds, the IOD used by each receiver and compare the IODs during post-test processing.

3.2.1.2.7.5 Aircraft GPS antenna location

The physical location of the GPS antenna on the aircraft will almost always be different than the aircraft reference point that represents the test aircraft position during noise measurements. This difference should be taken into account by adjusting the calculated aircraft X, Y, Z position coordinates from the GPS antenna location to the aircraft reference point.

This adjustment will typically include accounting for the flight direction relative to the ground reference coordinate system and, on large aircraft, may include accounting for the aircraft pitch attitude. The adjustment method and the locations of the aircraft reference point and the GPS antenna should be reported.

3.2.1.3 DGPS system approval recommendations

This section summarizes approval recommendations for DGPS-based TSPI systems proposed for use during noise certification tests.

3.2.1.3.1 Design issues

Each applicant's TSPI system design should address the issues identified in Table 3-1. The applicant's documentation (3.2.1.3.3) should address each item in the table.

Table 3-1. TPSI systems design development issues

Number	*Issue*	*Major considerations*
1	Selection of processing method (real-time versus post-test)	Need for aircraft guidance, ability to check test-run quality
2	Selection of solution method (carrier versus code)	Accuracy (favours carrier), site-specific multi-path testing requirements (favours carrier), acquisition cost (favours code)
3	Use of geodetic or waypoint coordinates	Waypoints can simplify post-processing but are not available for all receivers
4	Selection of GPS receiver and antenna	Items 1, 2, 3 and others (antenna multi-path control, data messages, solution latency, matched air/ground receivers, and IOD capability)
5	Selection of data link equipment (if real-time system)	Assigned frequency, data rate, error detection/ correction, flexible interface

3.2.1.3.2 Data storage (logging) during noise testing

3.2.1.3.2.1 For a system with real-time data link

For applicants employing a real-time data link, the ground-station GPS receiver should output RTCM/SC-104 Type-1 messages at a rate of 0.5 Hz or greater, which should be transmitted to, and used by, the aircraft GPS receiver. The airborne computer should collect data from the aircraft GPS receiver and generate permanent data files containing:

a) the three-dimensional aircraft position copied directly from the receiver's data port (i.e. in raw/native form) and not corrected or processed in any way;

b) if waypoint navigation is used, the waypoints (i.e. latitude, longitude and altitude) used to define the local coordinate frame;

c) the time (e.g. UTC or GPS time), with or without a local offset, associated with each sample of position data copied directly from the receiver's data port; and

d) the data quality/validity indication associated with each sample of position data.

If waypoints are used they should be included in the header of each data file. New waypoints should not be able to overwrite existing waypoints. If new waypoints are defined then a new data file should be created.

For consistency with the noise data collected during a certification test, it is recommended that the data associated with a), c) and d) above are saved in the GPS receiver's raw/native format at a rate of at least 2 Hz, the rate associated with the noise data. However, if hardware limitations do not make this possible, a sampling rate of 0.5 Hz or greater is acceptable.

3.2.1.3.2.2 For a system not using real-time data link

TSPI systems that do not use a real-time data link should save data from both the ground and aircraft GPS receivers in raw/native format in a permanent file for record keeping. Manufacturers' proprietary formats should be used. NMEA-type standard messages do not support this application.

Stored data should include: time (e.g. UTC or GPS time) with or without a local offset, satellite ephemeris, pseudo-range, signal-to-noise ratio, and carrier phase. If tropospheric delay is being modelled, as described in 3.2.1.2.6.2, then local meteorological conditions should be measured and stored as well. It is recommended that applicants using dual-frequency receivers also save the required L2 carrier phase data. Typically, post-processing of the ground-based and airborne GPS data will be performed using manufacturer-supplied software. If this is not the case then any applicant-developed software should be approved by the certificating authority.

3.2.1.3.3 Documentation

The applicant should prepare and submit documentation that includes:

a) *System description.* The issues described in Table 3-1 should be addressed, at a minimum.

b) *Hardware description.* Model and version number of all system components, including DGPS receivers, antennas, transceivers and computer.

c) *Software description.* Software functionality and capabilities, data file formats, hardware required and operating system.

d) *System setup and operation.* Ground and aircraft installation of the system including antennas, operating procedures, site survey procedures, power requirements and system limitations.

e) *Validating of the installation.* A method often used is to park the aircraft at a known, surveyed location and to read its position from the DGPS system. The installation can be verified from a comparison of the DGPS and surveyed positions. This can be performed either at the test site or at another location, such as the aircraft home base, if it is within 37 km (23 miles) of the test site. As a minimum this process should be performed at the start and end of each measurement programme and preferably at the beginning of each measurement day.

3.2.1.3.4 Accuracy verification test

The applicant should perform a one-time verification of the system accuracy, based on a minimum of six aircraft flight-test runs that encompass the conditions (i.e. speed, altitude, range and manoeuvres) for which the system will be later used as a reference. The accuracy verification test should involve a comparison of the DGPS-based TSPI system's position data with those from an accepted reference, such as another approved DGPS system. This test should be performed on the complete DGPS-based TSPI system developed by the applicant. It is not adequate for an applicant to simply cite prior approval of another applicant's system designed around the same GPS receiver.

3.2.1.3.5 Software verification

Prior to using the system during a noise measurement programme, any applicant-developed software for data logging and processing used to obtain TSPI data should be approved by the certificating authority. The approved software should be placed under version management.

3.2.1.3.6 Ground-station multi-path mitigation and verification

3.2.1.3.6.1 All systems

The ground-station GPS receiver antenna should have a choke ring, absorbing ground plane, or other multi-path-reducing technique. The antenna should be positioned on a pole or tower at a minimum height of 1.82 m (6 ft) above ground level.

3.2.1.3.6.2 Code-based systems

Prior to each measurement programme, applicants using code-based DGPS systems should perform a multi-path investigation at the test site using the ground-station receiver and antenna, as described in 3.2.1.2.6.2. The results of the investigation should be saved as part of the permanent test-series data archive and be made available for inspection by the certificating authority.

3.2.1.3.7 Test site survey

Additional information on survey requirements can be found in 3.2.1.2.2. Prior to and after the completion of each measurement programme, the applicant should use the DGPS-based TSPI system to survey the locations of:

a) all microphones and, if used, waypoints, if no other method of survey is used; or

b) a minimum of at least three points common to both methods if another method of survey is used.

Survey data should be stored as part of the measurement-programme permanent archive and included in the test report. If two survey methods are used, the common points should be reconciled to an accuracy of 0.3 m (1 ft) and the adjustment procedure submitted to the certificating authority for approval.

3.2.2 Photographic scaling

For a Chapter 10 or Chapter 11 test, a simpler system than DGPS that uses a lower sample rate has been found to be acceptable. Photographic scaling has been used successfully for this purpose. The method may be adapted for tests conducted under other chapters if additional equipment is used to obtain a sample rate of at least 0.5 Hz.

3.3 ON-BOARD FLIGHT DATA ACQUISITION

3.3.1 General

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 noise certification flight tests;

b) obtain data to adjust noise data; and

c) to synchronize flight, engine and noise data.

Typical parameters would include airspeed, climb angle, height/altitude, gross weight, flap position, landing gear position, jet-engine thrust (power) setting parameters (e.g. compressor rotor speed, engine pressure ratio and exhaust gas temperature), helicopter rotor speed, engine torque and propeller rotational speed.

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

a) manual recording;

b) magnetic tape recording;

c) digital recording;

d) automatic still photographic recording;

e) cine recording; and

f) video recording.

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

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

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

3.3.2 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 one-half-inch and one-inch magnetic tapes with a 24 to 28 volt DC power requirement. Six tape speeds as well as direct and FM recording are available in a tape recorder weighing about 27 kg (60 lb).

3.3.3 Automatic still photographic recording

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

3.3.4 Cine recording

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

3.3.5 Video recording

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

3.4 TIME SYNCHRONIZATION OF MEASURED DATA

3.4.1 General

Section 2.3.2 of Appendix 2 of the Annex specifies that there be precise time synchronization between noise measurements and aircraft position. Several methods have been used, such as noting the synchronization time on a clock mounted on the instrument panel that itself is recorded by the data acquisition system. One such system uses a ground camera that operates a radio transmission which, when received by an aircraft, lights two high-intensity light emitting diodes (LEDs) mounted in an analogue clock attached to the instrument panel. Other methods for acquiring and processing TSPI are described in subsequent sections.

A common time base should be used to synchronize noise, aircraft tracking and meteorological measurements. TSPI data should be determined at half-second intervals throughout the sound-measuring period (i.e. within 10 dB of maximum tone corrected perceived noise level (PNLTM)) by an approved method that is independent from systems installed aboard and normally used to control the aircraft. During processing, measured TSPI data should be interpolated, over time, to the time of sound emission of each half-second acoustic data record within the 10 dB-down period. Although the simplified procedure requires adjustment of only the PNLTM record to the reference flight path, sound emission coordinates should be determined for each half-second record for use in background noise adjustment procedures and for determination of incidence-dependent free-field microphone and windscreen corrections.

3.4.2 TSPI equipment and software approval

Some off-the-shelf TSPI equipment may require software enhancement to accommodate the specific installation. All TSPI equipment and software should be demonstrated to, and approved by, the certificating authority to ensure the system's operational accuracy.

3.4.3 Continuous time-code recording

This method uses a time-code signal, such as IRIG B, which is a modulated audio-frequency signal used for encoding time-base data developed by the Inter-Range Instrumentation Group (IRIG). In this method, the time-code signals from individual generators that have been synchronized to a common time-base are continuously recorded by both the noise data recorder(s) and by the TSPI system during measurement test runs. Synchronization of multiple generators can be performed either physically, by interconnecting via cable, or by means of radio transmission. The transmitted continuous time-code signal can be recorded directly, or used either continuously or in bursts to maintain synchronization of an independent time-code generator that is being recorded directly. This method allows for high-quality continuous time-code recording when there are intermittent reception problems.

Note 1.— Synchronization should be accomplished at the start of each measurement day and checked at the end of each measurement day to minimize the effects of generator time drift. Any such drift should be documented and accounted for in processing.

Note 2.— GPS-based measurement systems are often used for acquisition of TSPI data. GPS receivers are capable of providing the user with precise time-base information broadcast from the GPS satellite system, in some cases eliminating the need for a separate time-keeping device in the TSPI system.

Note 3.— For noise data recording or for non-GPS-based TSPI systems, dedicated IRIG B time-code generators are available that use the GPS signal to constantly update and maintain time synchronization. Use of such a universal broadcast time-base can greatly simplify the logistics of time synchronization between measurement systems.

Note 4.— There are two available time-bases for GPS-based systems: GPS Time and Coordinated Universal Time (UTC), whose values differ by more than 10 seconds at any given instant. Although the GPS signal includes both time-bases, not all GPS receivers give the user access to both. Therefore, the user should exercise caution in identifying which time-base is used by each instrument.

Note 5.— Many acoustical data recorders provide separate annotation channels in addition to the normal data channels. These channels are often not suitable for recording a modulated time-code signal because of limitations on dynamic range or bandwidth. In such cases a normal data channel of the recorder should be dedicated to recording the time-code signal.

Note 6.— When continuous time-code recording is used, analysis of the recorded acoustic data can be initiated by routing the time-code channel output into a time-code reader and triggering the analyser based on readout time.

3.4.4 Recording of single time marker

This method involves transmittal and recording of a radio “hack”, or tone, usually used to indicate the “recorders on” or “overhead” time instant. This method typically requires a dedicated channel on both the noise and the TSPI recording systems. When such a system is used, analysis can be triggered manually by an operator listening for the hack, or by a detector circuit responding to the tone. When the operator wishes to start analysis at a time other than that of the time marker, a stopwatch or delay circuit can be used to delay triggering of the analyser. When manual triggering is employed, the operator should use extreme care to perform the triggering as accurately as possible. Accuracy to within one-tenth of a second can be expected from a conscientious human operator.

3.4.5 Measurement of the interval between recorder start and overhead

This method of synchronization involves use of a stopwatch or elapsed-time indicator to measure the interval between start-up of the noise data recorder and the instant that the aircraft position is overhead the centre line noise measurement point. This method can be employed successfully as long as the operator exercises care in timing, the determination of the overhead instant is performed accurately, and the start-up characteristics of the recorder (in both record and playback modes) are known and repeatable. Some recorders have variable start-up times that cannot be predicted. Such recorders are not suitable for this method of synchronization.

3.4.6 Setting of internal time-stamp clock

Many digital recorders maintain a continuous internal time-of-day function by encoding time data in the recorded data stream. This method uses a digital recorder’s sub-code time, synchronized to the time-base used for the TSPI data. As with the continuous time-code recording method, synchronization by this method should be checked at the beginning and end of each measurement day and any drift accounted for in processing.

Unfortunately, the time-setting function on many recorders does not provide for the necessary precision. The “second” digits cannot be made to “tick” in synchrony with an external clock. Such recorders are unsuitable for this method of synchronization.

3.4.7 Additional time-synchronization considerations

Regardless of the synchronization method used, all elements affecting time synchronization, such as analyser start-up delay, head displacement between normal and annotation data channels on analogue recorders, and delays in automated triggering circuits, should be identified, quantified and accounted for in analysis and processing. Whenever human response to a timing event is required, errors cannot be accurately predicted, and conscientious operation is required to minimize such errors. The use of automated methods is preferred. Other methods, or variants of the listed methods, may be appropriate, but the use of all methods and instrumentation is subject to prior approval by the certificating authority.

3.5 CALCULATION OF CONFIDENCE INTERVALS

3.5.1 Introduction

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

a) flight test data;

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

c) analytical results; or

d) a combination thereof.

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

Sections 3.5.2 to 3.5.5 provide an insight into the theory of confidence interval evaluation. Application of this theory and some worked examples are provided in 3.5.6. A suggested bibliography is provided in Appendix 2 to this manual for those wishing to gain a greater understanding.

3.5.2 Confidence interval for the mean of flight test data

3.5.2.1 *Confidence interval for the sample estimate of the mean of clustered measurements*

If n measurements of EPNLs $y_1, y_2, ..., y_n$ 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:

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

s = estimate of the standard deviation of the mean

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

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

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

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

3.5.2.2 *Confidence interval for mean line obtained by regression*

If *n* measurements of EPNL ($y_1, y_2, ..., y_n$) are obtained under significantly varying values of engine-related parameter ($x_1, x_2, ..., x_n$), respectively, then a polynomial can be fitted to the data by the method of least squares. For determining the mean EPNL, μ , the following polynomial regression model is assumed to apply:

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

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

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

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

Each observation (x_i, y_i) satisfies the equations:

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

where ε_i and e_i are, respectively, the random error and residual associated with the EPNL. The random error ε_i is assumed to be a random sample from a normal population with mean zero and standard deviation σ. 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 σ. These equations are often referred to as the normal equations.

Table 3-2. Student's t-distribution (for 90 per cent confidence)

Degrees of freedom (ζ)	$t_{.95,\,\zeta}$
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

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:

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

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

A matrix $\underline{X}$ is formed from all the elemental vectors $\underline{x_i}$ for i = 1, ….., n. $\underline{X'}$ is the transpose of $\underline{X}$. A matrix is defined such that $\underline{A} = \underline{X'}\,\underline{X}$ and a matrix $\underline{A}^{-1}$ is the inverse of $\underline{A}$. In addition, $\underline{y} = (y_1\ y_2\ \ldots\ y_n)$, and $\underline{b} = (b_0\ b_1\ \ldots\ b_k)$, with $\underline{b}$ determined as the solution of the normal equations:

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

to give

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

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

$$\mathrm{CI}_{90} = \bar{y}\left(x_0\right) \pm t_{.95,\zeta}\ s\ v\left(x_0\right),$$

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

Thus $\mathrm{CI}_{90} = \bar{y}\left(x_0\right) \pm t_{.95,\zeta}\ s\ \sqrt{\underline{x}_0\,\underline{A}^{-1}\,\underline{x}'_0}$,

where:

- $\underline{x}_0 = \left(1\ x_0\ x_0^{\ 2}\ \ldots\ x_0^{\ k}\right)$;
- $\underline{x}'_0$ is the transpose of $\underline{x}_0$;
- $\bar{y}\left(x_0\right)$ is the estimate of the mean value of the EPNL at the associated value of the engine-related parameter;
- $t_{.95,\zeta}$ is obtained for ζ degrees of freedom. For the general case of a multiple regression analysis involving K independent variables (i.e. $K + 1$ coefficients) ζ is defined as $\zeta = n - K - 1$ (for the specific case of a polynomial regression analysis, for which k is the order of curve fit, there are k variables independent of the dependent variable, and so $\zeta = n - k - 1$); and
- $s = \sqrt{\dfrac{\sum_{i=1}^{i=n}\left(y_i - \bar{y}(x_i)\right)^2}{n - K - 1}}$, the estimate of the true standard deviation.

3.5.3 Confidence interval for static-test-derived NPD curves

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

$$\mathrm{EPNL}_{\mathrm{DF}} = \mathrm{EPNL}_{\mathrm{BF}} - \mathrm{EPNL}_{\mathrm{BS}} + \mathrm{EPNL}_{\mathrm{DS}},$$

or using the notation adopted above:

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

where:

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 EPNL at engine-related parameter x_0, i.e. for $\mu_{\mathrm{DF}}(x_0)$, is given by:

$$\mathrm{CI}_{90}\left(x_0\right) = \bar{y}_{\mathrm{DF}}(x_0) \pm t' v_{\mathrm{DF}}(x_0)$$

where:

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

with s_{BF}, s_{BS}, s_{DS}, $v_{\mathrm{BF}}(x_0)$, $v_{\mathrm{BS}}(x_0)$, $v_{\mathrm{DS}}(x_0)$ computed as explained in 3.5.2.2 for the respective data sets indicated by the subscripts BF, BS and DS, and

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

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

3.5.4 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 (Δ) 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 3.5.2 and 3.5.3.

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*, such that:

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

where *d* is assumed to be normally distributed with mean zero and known variance τ^2, then the confidence interval for

$\mu(x_0) + \Delta$ is given by:

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

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

3.5.5 Adequacy of the model

3.5.5.1 ***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.

3.5.5.2 ***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 using a higher order polynomial.

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

3.5.6 Worked example of the determination of 90 per cent confidence intervals from the pooling of three data sets

3.5.6.1 ***Introduction***

This section presents an example of the derivation of the 90 per cent confidence intervals arising from the pooling of three data sets. Worked examples and guidance material are presented for the calculation of confidence intervals for a clustered data set as well as for first order (i.e. straight line) and second order (i.e. quadratic) regression curves. In addition this section also shows how the confidence interval shall be established for the pooling together of several data sets.
Consider the theoretical evaluation of the certification noise levels for an aircraft retrofitted with silenced engines. The approach noise level for the "flight datum" aircraft was derived from a clustered data set of noise levels measured at nominally reference conditions, to which were added source noise corrections derived from a quadratic least-squares curve fit through a series of data points made at different engine thrusts. In order to evaluate the noise levels for the aircraft fitted with acoustically treated engines, a further source noise curve, assumed to be a straight least-squares regression line, was established from a series of measurements of the silenced aircraft. Each of the three databases is assumed to be made up of data unique to each base.

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

The two curves that determine the acoustical changes are the regression curves (in this example quadratic and straight-line least-squares fit curves) for the plots of EPNL against normalized thrust for the hardwall and silenced conditions. These are presented in Figure 3-3 where the dotted lines plotted about each line represent the boundaries of 90 per cent confidence.

Each of the two curves is made up of 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 maintained that the number of data points in each of the three sets is large enough to constitute a statistical sample.

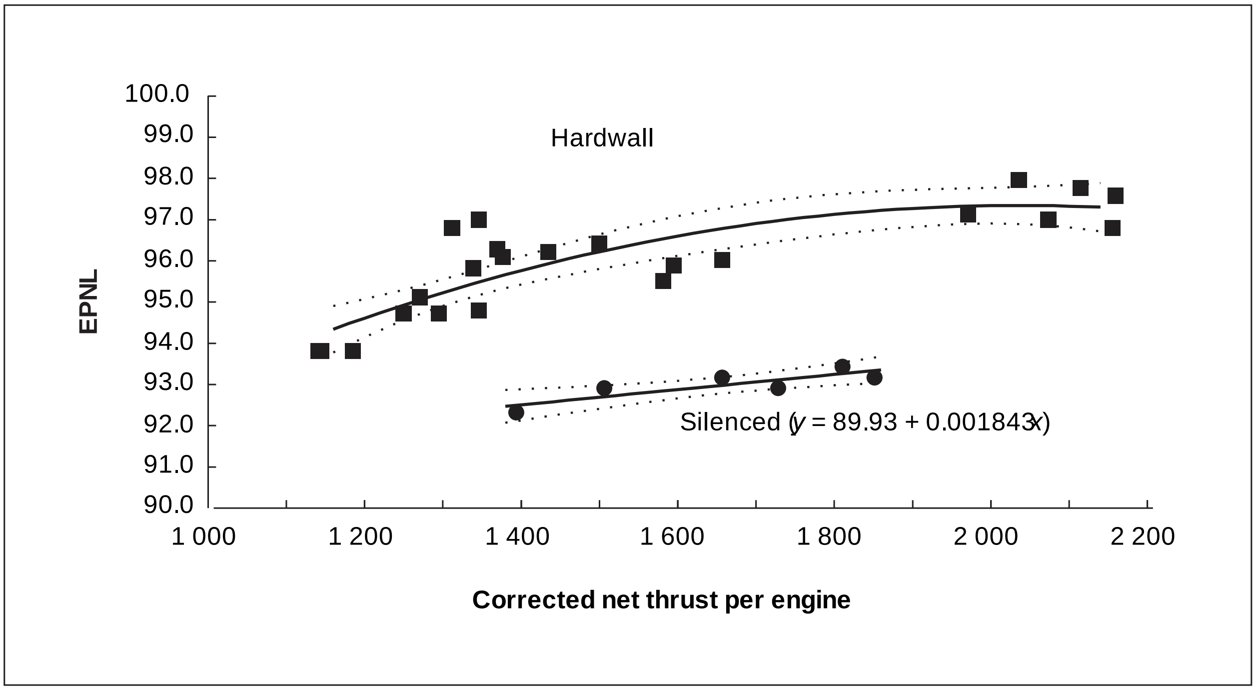


Figure 3-3. Regression curves for plots of EPNL against normalized thrust for hardwall and silenced conditions

3.5.6.2 ***Confidence interval for a clustered data set***

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

Let EPNL_i be the individual values of EPNL,

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

Then the confidence interval $\text{CI} = \overline{\text{EPNL}} \pm t\frac{s}{\sqrt{n}}$, where s, the estimate of the standard deviation, is defined as:

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

$$\overline{\text{EPNL}} = \frac{\sum_{i=1}^{i=n} \text{EPNL}_i}{n} .$$

Suppose that the clustered set of EPNL values consists of the following:

Run number	*EPNL*
1	95.8
2	94.8
3	95.7
4	95.1
5	95.6
6	95.3

Then the number of data points (n) = 6, the degrees of freedom ($n-1$) = 5, and the Student's t-distribution for 5 degrees of freedom = 2.015 (see Table 3-2), and so:

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

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

and the confidence interval (CI) is calculated as follows:

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

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

Suppose that the regression curve for one of the source noise data sets, the silenced case, can best be represented by a straight line least-squares fit curve (i.e. 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, in this case normalized thrust $F_N / \delta_{\text{amb}}$.

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

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

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

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

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

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

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

where:

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

$$\underline{x_0} = \begin{pmatrix} 1 & x_0 \end{pmatrix};$$

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

$\underline{A}^{-1}$ is the inverse of $\underline{A}$ where $\underline{A} = \underline{X'X}$, with $\underline{X}$ and X' defined as in 3.5.2.2 from the elemental vectors formed from the measured values of the independent variable X_i; and

$s = \sqrt{\dfrac{\sum_{i=1}^{i=n} (\Delta Y)_i{}^2}{n-k-1}}$ 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 straight line least-squares fit curve for $X = X_i$, and *n* and k are defined as the number of data points and the order of the polynomial regression line, respectively.

Suppose that the data set consists of the following set of six EPNL values, together with their associated values of engine-related parameter (see Table 3-3). Note that it would be usual to have more than six data points making up a source noise curve, but in order to limit the size of the matrices in this example, the number of data points has been restricted.

By plotting this data (see Figure 3-3) it can be seen by examination that a linear relationship between EPNL (the dependent variable *Y*) and $F_N / \delta_{\text{amb}}$. (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
1 395	92.3	128 759	1 946 025
1 505	92.9	139 815	2 265 025
1 655	93.2	154 246	2 739 025
1 730	92.9	160 717	2 992 900
1 810	93.4	169 054	3 276 100
1 850	93.2	172 420	3 422 500
$\sum X$	$\sum Y$	$\sum XY$	$\sum X^2$
9 945	557.9	925 010	16 641 575

$$a = \frac{\sum_{i-1}^{i=n} Y_i - b\sum_{i=1}^{i=n} X_i}{n} = \frac{557.9 - (0.001843)(9\,945)}{6} = \underline{\underline{89.93}}\text{; and}$$

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

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

$$= \frac{92\,5010}{6} - \frac{(9\,945)(557.9)}{36} = 48.46\text{; and}$$

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

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

$$b = \frac{48.46}{26\,289.6} = \underline{\underline{0.001843}}.$$

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

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

and is calculated as follows. From the single set of measured independent variables tabulated in Table 3-3, the matrix, $\underline{X}$, is formed from the elemental row vectors such that:

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

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

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

The matrix $\underline{A}$ is now formed, defined such that $\underline{A} = \underline{X}'\underline{X}$, and so:

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

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

$$\underline{A}^{-1} = \begin{pmatrix} 17.5836 & -0.01051 \\ -0.01051 & 6.3396\times10^{-6} \end{pmatrix}.$$

Note.— The manipulation of matrices (i.e. their multiplication and inversion) is best performed by computers via standard routines. Such routines are possible using standard functions contained within many commonly used spreadsheets.

Table 3-3. Values of sample data set

Run number	$F_N / \delta_{\text{amb}}$	*EPNL*
1	1 395	92.3
2	1 505	92.9
3	1 655	93.2
4	1 730	92.9
5	1 810	93.4
6	1 850	93.2

To find the 90 per cent confidence interval about the regression line for a value of F_N / δ (i.e. x_0) of 1 600, the row vector $(\underline{x_0})$ and its transpose $(\underline{x_0}')$, a column vector, are formed such that:

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

and

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

From the calculation of $\underline{A}^{-1}$ one obtains:

$$\underline{x_0}\,\underline{A}^{-1} = \begin{pmatrix} 1 & 1\,600 \end{pmatrix} \begin{pmatrix} 17.5836 & -0.01051 \\ -0.01051 & 6.3396\times10^{-6} \end{pmatrix}$$

$$= \begin{pmatrix} 0.7709 & -3.6453\times10^{-4} \end{pmatrix},$$

and so:

$$\underline{x_0}\,\underline{A}^{-1}\,\underline{x_0}' = \begin{pmatrix} 0.7709 & -3.6453\times10^{-4} \end{pmatrix} \begin{pmatrix} 1 \\ 1\,600 \end{pmatrix} = 0.1876\,.$$

The equation for confidence interval also requires the value of standard deviation for the measured data set to be evaluated. From Table 3-3 and the regression equation for the least-squares best fit straight line, from which is calculated the predicted value of EPNL at each of the six measured values of F_N / δ, one proceeds as follows:

Run number	F_N/δ	EPNL *(Measured)*
1	1 395	92.3
2	1 505	92.9
3	1 655	93.2
4	1 730	92.9
5	1 810	93.4
6	1 850	93.2

Run number	EPNL *(Predicted)*	$(\Delta\text{EPNL})^2$
1	92.50	0.03979
2	92.70	0.03911
3	92.98	0.04896
4	93.12	0.04708
5	93.26	0.01838
6	93.34	0.01909

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

for n = 6 and k = 1.

Taking the value of Student's t-distribution from Table 3-2 for $(n-k-1)$ degrees of freedom (i.e. 4) to be 2.132, the confidence interval about the regression line at F_N/δ = 1 600 is defined as follows:

$$\text{CI}_{90} = \overline{\text{EPNL}} + ts\sqrt{\underline{x_0}\,\underline{A^{-1}}\,\underline{x_0}'}$$

$$= 92.88 \pm (2.132)(0.2304)\sqrt{0.1876}$$

$$= 92.88 \pm 0.2128.$$

In order to establish the lines of 90 per cent confidence intervals about a regression line, the values of CI_{90} for a range of values of independent variable(s) should be calculated, through which a line can be drawn. These lines are shown as the dotted lines in Figure 3-3.

3.5.6.4 *Confidence interval for a second order regression curve*

The confidence intervals for a second order regression curve are derived in a similar manner to those for a straight line detailed in 3.5.6.3. A detailed example of their calculation is not discussed here. 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:

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

are formed from 1 × 3 and 3 × 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 (i.e. with $(K+1)$ coefficients, including the constant term) is defined as $(n-K-1)$. For a second order regression curve, there are two independent variables and so the number of degrees of freedom is $(n-3)$.

3.5.6.5 *Confidence interval for the pooled data set*

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

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

where

$$Z_i = \frac{\mathrm{CI}_i}{t_i}\,,$$

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

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

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

The different stages in the calculation of the confidence interval at the reference thrust of $F_N / \delta_{\mathrm{amb}} = 1\ 600$ for the pooling of the three data sets are summarized in Table 3-4.

Table 3-4. Example of confidence interval calculation

Description	*Function*	*Datum*	*Hardwall*	*Silenced*
Reference thrust	F_N / δ_{amb}		1 600	1 600
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-distribution	t	2.015	1.725	2.132
Z	CI_{90}/t	0.1580	0.2792	0.09981
Z^2	$\left(CI_{90}/t\right)^2$	2.4953×10^{-2}	7.7979×10^{-2}	9.9625×10^{-3}
$Z^2 t$	$\left(CI_{90}/t\right)^2 t$	5.0280×10^{-2}	0.1345	2.1240×10^{-2}
$\sum Z^2$			0.1129	
$\sum\left(Z^2 t\right)$			0.2060	
T	$\sum\left(Z^2 t\right) / \sum Z^2$		1.8248	
$\sqrt{\sum Z^2}$			0.3360	
CI	$T\sqrt{\sum Z^2}$		0.6131	

3.5.7 Student's t-distribution (for 90 per cent confidence) for various degrees of freedom

The values in the Student's t-distribution to give a probability of 0.95 that the population mean value (μ) is such that:

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

and thus a probability of 90 per cent that:

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

are tabulated in Table 3-2.

3.6 ADJUSTMENT OF AIRCRAFT NOISE LEVELS FOR THE EFFECTS OF BACKGROUND NOISE

3.6.1 Introduction

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

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

a) testing to determine which portions of the spectral time history, if any, are obscured;

b) adjustment of unobscured levels to determine the aircraft sound levels that would have been measured in the absence of background noise; and

c) replacement or reconstruction of obscured levels by frequency extrapolation, time extrapolation or other means.

Definitions of the terms used in this section are provided in 3.6.2. Although some of the terms have generally accepted meanings, the specific meanings as defined apply herein.

A detailed step-by-step procedure is presented in 3.6.3 including equations and descriptions of time and frequency extrapolation methods (see 3.6.3.2.10). Other procedures may be used provided that they have been approved by the certificating authority.

General considerations that apply to any background noise adjustment procedure are listed in 3.6.4, including limitations and requirements (see 3.6.4.1) and other special considerations (see 3.6.4.2 through 3.6.4.4).

3.6.2 Definitions

For the purposes of 3.6, the following definitions apply:

Adjusted level. A valid one-third octave band level that has been adjusted for measurement conditions, including:

a) the energy contribution of pre-detection noise; and

b) frequency-dependent adjustments such as system frequency response, microphone pressure response and free-field response, and windscreen incidence-dependent insertion loss.

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

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

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

$$10\ \log\left[10^{(SPL_1/10)}-10^{(SPL_2/10)}\right],$$

where SPL_1 and SPL_2 are two sound pressure levels in decibels, with SPL_2 being the value subtracted from SPL_1.

Frequency extrapolation. A method for reconstruction of high frequency masked data, based on unmasked data in a lower-frequency one-third octave band from the same spectrum.

High frequency bands. The twelve bands from 800 Hz through 10 kHz inclusive (also see “low frequency bands”).

Last good band (LGB). In the adjustment methodology presented in 3.6.3, for any aircraft one-third band spectrum, the LGB is the highest frequency unmasked band within the range of 630 Hz to 10 kHz inclusive, below which there are no masked high frequency bands.

Low frequency bands. The twelve bands from 50 Hz through 630 Hz inclusive (also see “high frequency bands”).

Masked band. Within a single spectrum, any one-third octave band containing a masked level.

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

Masking criteria. The spectrum of one-third octave band levels below which measured aircraft sound pressure levels are considered to be masked or obscured by background noise. Masking criteria levels are defined as the greater of:

a) pre-detection noise + 3 dB; or

b) post-detection noise + 1 dB.

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

Pre-detection noise. Any noise that can contribute energy to the measured levels of sound produced by the aircraft, including ambient noise present at the microphone site and active instrumentation noise present in the measurement, record/playback and analysis systems.

Reconstructed level. A level, calculated by frequency extrapolation, time extrapolation, or by other means, which replaces the measured value for a masked band.

Sound attenuation coefficient. The reduction in level of sound within a one-third octave band, in dB per 100 metres, due to the effects of atmospheric absorption of sound.

Time extrapolation. A method for reconstruction of high frequency masked data, based on unmasked data in the same one-third octave band, from a different spectrum in the time history.

Valid or unmasked band. Within a single spectrum, any one-third octave band containing a valid level.

Valid or unmasked level. Any one-third octave band level that exceeds the masking criterion for that band.

3.6.3 Background noise adjustment procedure

3.6.3.1 *Assumptions*

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

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

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

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

3.6.3.2 *Step-by step description*

3.6.3.2.1 Determination of pre-detection noise

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

3.6.3.2.2 Determination of post-detection noise

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

3.6.3.2.3 Testing of pre-detection noise versus post-detection noise

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

3.6.3.2.4 Determination of masking criteria

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

3.6.3.2.5 Identification of masked levels

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

3.6.3.2.6 Determination of Last Good Band (LGB)

For each half-second spectral record, determine the highest frequency unmasked one-third octave band (“Last Good Band” or “LGB”) by starting at the 630 Hz band and incrementing the band number (i.e. increasing frequency) until a masked band is found. At that point, set LGB for that spectral record equal to the band below the masked band. The lowest frequency band that can be identified as LGB is the 630 Hz band. In other words, if both the 630 Hz band and the 800 Hz band are masked, no reconstruction of masked levels may be performed for that spectrum, and the thirteen bands between 630 Hz and 10 kHz inclusive should be left as is and identified as masked. According to the masking limits specified in 3.6.4.2 a), such a spectrum is not valid for calculation of EPNL when it occurs within the 10 dB-down period.

3.6.3.2.7 Adjustment of valid levels for background noise

In each half-second spectrum, for each valid band up to and including LGB, perform an energy-subtraction of the valid pre-detection level from the valid measured level in the aircraft noise time history using:

$$10\ \log\ \left[10^{(SPL_{\text{AIRCRAFT}}/10)} - 10^{(SPL_{\text{PRE-DETECTION}}/10)}\right]$$

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

3.6.3.2.8 Adjustment of valid levels for measurement conditions

Before any reconstruction can be done for masked levels, valid levels that have been adjusted for the presence of pre-detection noise must also then be adjusted for frequency-dependent adjustments such as system frequency response, microphone pressure response and free-field response, and windscreen incidence-dependent insertion loss. These adjustments cannot be applied to masked levels.

3.6.3.2.9 Reconstruction of low frequency masked bands

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

3.6.3.2.10 Reconstruction of high frequency masked bands

Frequency extrapolation and time extrapolation are the methods used to reconstruct masked one-third octave band levels for bands at frequencies higher than LGB for each spectral record. One-third octave band sound attenuation coefficients (either in dB per 100 m or in dB per 1 000 ft) must be determined before such reconstruction of masked band levels can be performed. Note that sound emission coordinates must also be calculated for each record before reconstruction is performed since the procedure is dependent on propagation distance.

3.6.3.2.10.1 *Frequency extrapolation method*

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

$$\begin{aligned}\mathrm{SPL_X}(i,k) = {}& \mathrm{SPL}(i_{\mathrm{LGB}},k) + \alpha(i_{\mathrm{LGB}}) \times \frac{\mathrm{SR}(k)}{100} - \alpha_{\mathrm{R}}(i_{\mathrm{LGB}}) \times \frac{60}{100} + 20\log\frac{\mathrm{SR}(k)}{60} \\ & + \alpha_{\mathrm{R}}(i) \times \frac{60}{100} - \alpha(i) \times \frac{\mathrm{SR}(k)}{100} + 20\log\frac{60}{\mathrm{SR}(k)}\end{aligned}$$

which can be reduced to:

$$\mathrm{SPL_X}(i,k) = \mathrm{SPL}(i_{\mathrm{LGB}},k) + \left[\alpha(i_{\mathrm{LGB}}) - \alpha(i)\right]\frac{\mathrm{SR}(k)}{100} + \left[\alpha_{\mathrm{R}}(i) - \alpha_{\mathrm{R}}(i_{\mathrm{LGB}})\right]\frac{60}{100},$$

where:

— i is the masked band to be extrapolated;

— k is the record of interest;

— i_{LGB} is the LGB in record k;

— $\mathrm{SPL_X}(i)$ is the frequency-extrapolated level in dB for masked band i and spectral record k;

— $\mathrm{SPL}(i_{\mathrm{LGB}},k)$ is the level for LGB in record k after all test-day adjustments have been applied, including pre-detection noise energy-subtraction, system and microphone adjustments, etc.;

— $\alpha(i_{\mathrm{LGB}})$ is the test-day sound attenuation coefficient (dB per 100 m) for LGB;

— $\alpha(i)$ is the test-day sound attenuation coefficient (dB per 100 m) for band i;

— $\alpha_R(i_{LGB})$ is the reference (25°C (77°F), 70 per cent relative humidity (RH)) sound attenuation coefficient (dB per 100 m) for LGB;

— $\alpha_R(i)$ is the reference (25°C (77°F), 70 per cent RH) sound attenuation coefficient (dB per 100 m) for masked band i; and

— SR(k) is the slant range or sound propagation distance in metres at the time of sound emission for spectral record k, between the aircraft and the microphone.

This procedure is based on the assumption that the aircraft spectrum is "flat" (i.e. all high frequency band levels are equal) at a distance of 60 m (197 ft) under reference conditions (25°C (77°F), 70 per cent RH). The process can be conceptualized by means of the following steps:

a) the level for band i_{LGB}, the highest frequency unmasked band in spectral record k, which has already been adjusted for measurement conditions, is adjusted for test-day propagation effects to obtain the source level and then adjusted using reference propagation effects to the 60 m (197 ft) distance from the source;

b) this level is then assigned as the level for all high frequency masked bands (i.e. band i, band i + 1, etc.) at a distance of 60 m (197 ft);

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

d) the extrapolated level that would have been measured on the ground, in the absence of background noise, is determined for each masked high frequency band by adding the test-day propagation effects to each of the source levels determined in c) above.

3.6.3.2.10.2 *Time extrapolation method*

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

$$\mathrm{SPL_X}(i,k) = \mathrm{SPL}(i,m) + \alpha(i)\left[\frac{\mathrm{SR}(m)}{100} - \frac{\mathrm{SR}(k)}{100}\right] + 20\log\left[\frac{\mathrm{SR}(m)}{\mathrm{SR}(k)}\right]$$

where:

— $\mathrm{SPL_X}(i,k)$ is the time-extrapolated level in dB for masked band i and spectral record k;

— SPL(i,m) is the adjusted level in dB for band i in spectral record m, which is the nearest record in time to record k in which band i contains a valid level;

— SR(m) is the slant range or sound propagation distance in metres at the time of sound emission for spectral record m, between the aircraft and the microphone;

— SR(k)is the slant range or sound propagation distance in metres at the time of sound emission for spectral record k, between the aircraft and the microphone; and

— $\alpha(i)$ is the test-day sound attenuation coefficient (dB per 100 m) for band i.

This procedure is based on the assumption that the aircraft spectrum is omnidirectional during the aircraft pass-by.

Note.— When using the time-extrapolation method of reconstruction, avoid extrapolating from a previously-reconstructed SPL. The closest valid SPL in a particular band may not be time-adjacent to the SPL being reconstructed.

Note.— If there is no valid SPL in a particular band from which to extrapolate (i.e. all SPLs in that band during the test run are masked), then the nearest SPL in that band that has been reconstructed using the frequency extrapolation method should be used. This deviation from the provided time extrapolation method should be documented in the noise compliance report if the time-extrapolated level occurs within the 10 dB down period.

3.6.3.2.11 Handling of spectra after reconstruction of masked bands

After reconstruction of masked data has been performed, the background noise adjustment procedure is complete. The adjusted as-measured data set, comprised of adjusted levels, reconstructed levels, and possibly some masked levels, is next used to obtain the test-day PNLT time history described in 4.3 of Appendix 2 of the Annex. The identification of masked data should be kept accessible for use during the tone correction procedure, since any tone correction that results from the adjustment for background noise may be eliminated from the process of identifying the maximum tone within a spectrum. When this background noise adjustment procedure is used, the band identified as LGB should be treated as the last band of the tone correction calculation in the manner prescribed for the 10 kHz band in 4.3.1 of Appendix 2 of the Annex, including the calculation of a new slope for band LGB + 1 that equals the slope at LGB (i.e. $s'(i_{LGB} + 1,k) = s'(i_{LGB},k)$) in Step 5 of the tone correction procedure.

3.6.4 General considerations

3.6.4.1 ***Limitations and requirements for any background noise adjustment procedure***

Any method of adjusting for the effects of background noise must be approved by the certificating authority before it is used. The adjustment procedure presented in 3.6.3.2 includes applicable limitations and requirements. Those limitations and requirements that apply to all methodologies are described as follows.

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

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

When consecutive one-third octave bands in the range of 2.5 kHz to 10 kHz inclusive are masked, and when no consecutive bands are masked in the region of 800 Hz to 2 kHz inclusive, frequency extrapolation, as described in 3.6.3.2.10.1, must be performed on all consecutive masked bands with nominal frequencies greater than 2 kHz.

When consecutive one-third octave bands in the range of 800 Hz to 2 kHz inclusive are masked, time extrapolation, as described in 3.6.3.2.10.2, must be performed on all consecutive masked bands with nominal frequencies greater than 630 Hz.

In cases where a single masked one-third octave band occurs between two adjacent valid bands, the levels of the adjacent adjusted bands may be arithmetically averaged and the averaged level used in place of the masked level. If the masked level is retained it must be included when counting the masked levels in the procedure described in 3.6.4.2.

3.6.4.2 ***Rejection of spectra due to masking***

A spectrum becomes invalid if the following conditions prevail:

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

b) for records within one second of the record associated with the PNLTM spectrum (i.e. five half-second data records) if:

1) more than four high frequency bands require reconstruction; or

2) the LGB is located at or below the 3 150 Hz one-third octave band when the example background noise adjustment procedure presented in 3.6.3.2 is used.

Note.— If an invalid spectrum occurs within the 10 dB-down period, the aircraft test run is invalid and cannot be used for aircraft noise certification purposes.

3.6.4.3 ***Special tone correction considerations due to masking***

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

a) when the example background noise adjustment procedure presented in 3.6.3.2 is used or, specifically, when all of the high frequency bands in a spectrum are masked for frequencies beyond a certain band (i.e. "LGB") the band labelled as LGB should be treated as the last band of the tone correction calculation, in the manner prescribed for the 10 kHz band (band number 24) in 4.3.1 of Appendix 2 of the Annex, including calculation of a new slope for the band above LGB that equals the slope of the band at LGB (i.e. $s'(i_{\mathrm{LGB}} + 1,k) = s'(i_{\mathrm{LGB}},k)$) in Step 5 of the tone correction procedure; or

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

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

3.6.4.4 ***Handling of masked data in reference conditions data sets***

For any one-third octave band spectrum adjusted to reference conditions, all bands, including those containing masked levels or reconstructed levels, including values less than 0 dB, must be adjusted for differences between test and reference conditions (i.e. atmospheric absorption and spherical spreading). The special tone correction considerations listed in 3.6.3.2 apply both to test and reference data sets.

3.7 NOISE REDUCTION SYSTEMS

An aircraft can employ noise reduction systems that change its configuration or operating condition to reduce noise, or implement devices or subsystems that directly reduce or counteract sound emissions. Two categories, variable noise reduction systems (VNRS) and selectable noise reduction systems (SNRS), have been defined to address differences in activation/actuation for these systems. General guidance on noise certification of aircraft equipped with these systems is provided below.

3.7.1 Variable noise reduction systems

A VNRS is an integral design feature, or subsystem, of an aircraft that automatically changes the configuration or operating condition of the aircraft to reduce noise.

Note 1.— If pilot action is necessary to activate, i.e. select the use of, an automatically controlled noise reduction system or if a pilot can deactivate (deselect) an automatically controlled noise reduction system, such a system is not considered a VNRS.

Note 2.— Aircraft can incorporate variable systems, primarily intended to improve performance, reduce engine emissions and/or increase safety, that may also affect noise. Such aircraft can be noise certificated using the guidance provided for aircraft with VNRS. For such changes to existing type designs, the guidelines provided in 2.3, for "no-acoustical changes" are applicable.

For a VNRS-equipped aircraft, the VNRS characteristics may prevent flight from being conducted in accordance with the associated reference procedure(s) in the Annex. In such cases, the reference procedures for noise certification of an aircraft with a VNRS should depart from those specified in the Annex only to the extent required by those design characteristics that cause the departure and should be approved by the certificating authority (see 3.6.1.4, 5.6.1.4, 8.6.1.4 and 10.5.1.3 of the Annex).

The impact of a VNRS on noise certification of an aircraft can extend beyond deviations from the Annex 16, Volume I, reference procedures. A plan for noise certification of a VNRS-equipped aircraft should take into consideration three key elements, namely:

a) the necessity, if any, to depart from the Annex reference procedures;

b) the adaptation/modification of test procedures to ensure compliance with Annex requirements; and

c) the applicability of existing procedures in the Annex for adjusting the measured data to reference conditions.

Experience to date has shown that one or more of these elements may be interrelated, requiring detailed consideration of all three elements in devising an acceptable plan for noise certification.

3.7.1.1 ***Reference procedures***

The Annex reference procedures typically utilize constant flight path and operational parameters. A VNRS can, however, result in non-constant reference flight paths and/or non-constant operational parameters such as non-constant rates of climb and/or non-constant engine/propeller/rotor speeds, respectively, that compel departure from the reference procedures. In addition to reducing noise emissions, a VNRS may, and typically does, impact aircraft performance during a noise certification reference procedure. In some cases, this impact can be indirect via another affected performance parameter. Both direct and indirect impacts on aircraft performance should be addressed in defining any departure necessary from the reference procedures in the Annex to accommodate a VNRS.

Actuation of a VNRS can be a function of one or more operational conditions such as airspeed, ground speed, height above ground level, density altitude, pressure altitude and ambient temperature. Beginning and end points on the reference flight path for any transition triggered by a VNRS should be determined using the reference test and meteorological conditions.

3.7.1.2 *Test conditions and procedures*

When a VNRS results in a non-constant reference flight path for the aircraft, the flight path tolerances (height and lateral deviation limits) specified in the Annex for the corresponding constant reference procedure should be applied, subject to approval by the certificating authority. Similarly, when a VNRS results in a non-constant operational parameter for the aircraft, a reference schedule for the affected operating parameter should be defined along the reference flight path, and the test tolerances permitted by the Annex for that parameter should be applied to the reference schedule, subject to approval by the certificating authority.

3.7.1.3 *Adjustments to measured noise data*

Adjustments to measured data in the Annex are based on constant reference procedures. A VNRS can, however, result in a non-constant reference procedure(s) that in turn impacts the adjustments to measured data that account for test deviations from reference flight profiles and test conditions. The adjustments to measured data specified in the Annex should be modified only as necessary to account for any departures from the reference procedures in the Annex. In many cases, only minor changes to data-processing software that do not affect the adjustment procedures will be needed. Any modifications, including software revisions, of the adjustments to measured data specified in the Annex are subject to approval by the certificating authority.

3.7.1.4 *Environmental Technical Manual guidance for specific VNRS*

Specific guidance for VNRS technologies will typically be developed as these technologies are developed and implemented in aircraft designs. Cross references to the appropriate sections of this manual for the VNRS technologies for which specific guidance has been generally accepted by certificating authorities are provided in Table 3-5.

Table 3-5. Cross references to specific guidelines in this manual for VNRS

Variable noise reduction system (VNRS)	*Applicable chapter/appendix of the Annex*	*Specific guidelines provided in this manual*
Variable rotor speed helicopters	Chapter 8/Appendix 2	4.1.8 AMC No. 2 A2 8.1.2 [Take-off flight test procedures], paragraph 8)

3.7.2 Selectable noise reduction systems

(Reserved)

Note.— The guidance provided in 3.7 addresses VNRS only and, by inference, defines as selectable all noise reduction systems that do not satisfy the requirements for classification as VNRS. Guidance specific to SNRS, including a definition specific to SNRS, is not yet provided.

3.8 CALCULATION OF THE SPEED OF SOUND

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

$$c = 343.2\ (T/T_0)^{1/2}\ \text{m/s, or}$$

$$c = 1\ 125.9\ (T/T_0)^{1/2}\ \text{ft/s,}$$

where T_0 = 293.15 K and T is the ambient air temperature in kelvin.

Note.— At the noise certification reference temperature of 25°C, T = 298.15 K, and c_R therefore equals 346.1 m/s (1 135.5 ft/s).

3.9 REFERENCE TABLES USED IN THE MANUAL CALCULATION OF EFFECTIVE PERCEIVED NOISE LEVEL

Tables 3-6 and 3-7 and Figure 3-4 contain information useful for the manual calculation of EPNL. Such manual calculations are often used to verify the accuracy of computer programs used for calculating certification noise levels.

Table 3-6. Perceived noisiness (noys) as a function of sound pressure level

One-third octave band centre frequencies (Hz)

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

One-third octave band centre frequencies (Hz)

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

One-third octave band centre frequencies (Hz)

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

Table 3-7. 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	$\lvert\Delta s\rvert$ 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	$-2\frac{1}{3}$	70	—	
4	100	62	–8	—	62	–8	$+3\frac{1}{3}$	$67\frac{2}{3}$	—	
5	125	70	+8	16	71	+9	$+6\frac{2}{3}$	71	—	
6	160	80	+10	2	80	+9	$+2\frac{2}{3}$	$77\frac{2}{3}$	$2\frac{1}{3}$	0.29
7	200	82	+2	8	82	+2	$-1\frac{1}{3}$	$80\frac{1}{3}$	$1\frac{2}{3}$	0.06
8	250	83	+1	1	79	–3	$-1\frac{1}{3}$	79	4	0.61
9	315	76	–7	8	76	–3	$+\frac{1}{3}$	$77\frac{2}{3}$	—	
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	–1⁄3	79	—	
14	1 000	80	+2	3	80	+2	–2⁄3	78 2⁄3		
15	1 250	78	–2	4	78	–2	–1⁄3	78	—	
16	1 600	76	–2	0	76	–2	+1⁄3	77 2⁄3	—	
17	2 000	79	+3	5	79	+3	+1	78		
18	2 500	85	+6	3	79	0	–1⁄3	79	6	2
19	3 150	79	–6	12	79	0	–2 2⁄3	78 2⁄3	—	
20	4 000	78	–1	5	78	–1	–6 1⁄3	76	2	0.33
21	5 000	71	–7	6	71	–7	–8	69 2⁄3	—	
22	6 300	60	–11	4	60	–11	–8 2⁄3	61 2⁄3	—	
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 A2-2 of Appendix 2 of the Annex

Note.— Steps 5 and 6 may be eliminated in the calculations if desired. In this case in the example shown, 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 of Appendix 2 of the Annex are then replaced by:

STEP 5 [6 (*i* – 1) + 6 *i* 6 (*i* + 1)] ÷ *3*

STEP 6 (3 7 (*i*) *if > 0*

STEP 7 *See Table A2-2 of Appendix 2 of the Annex.*

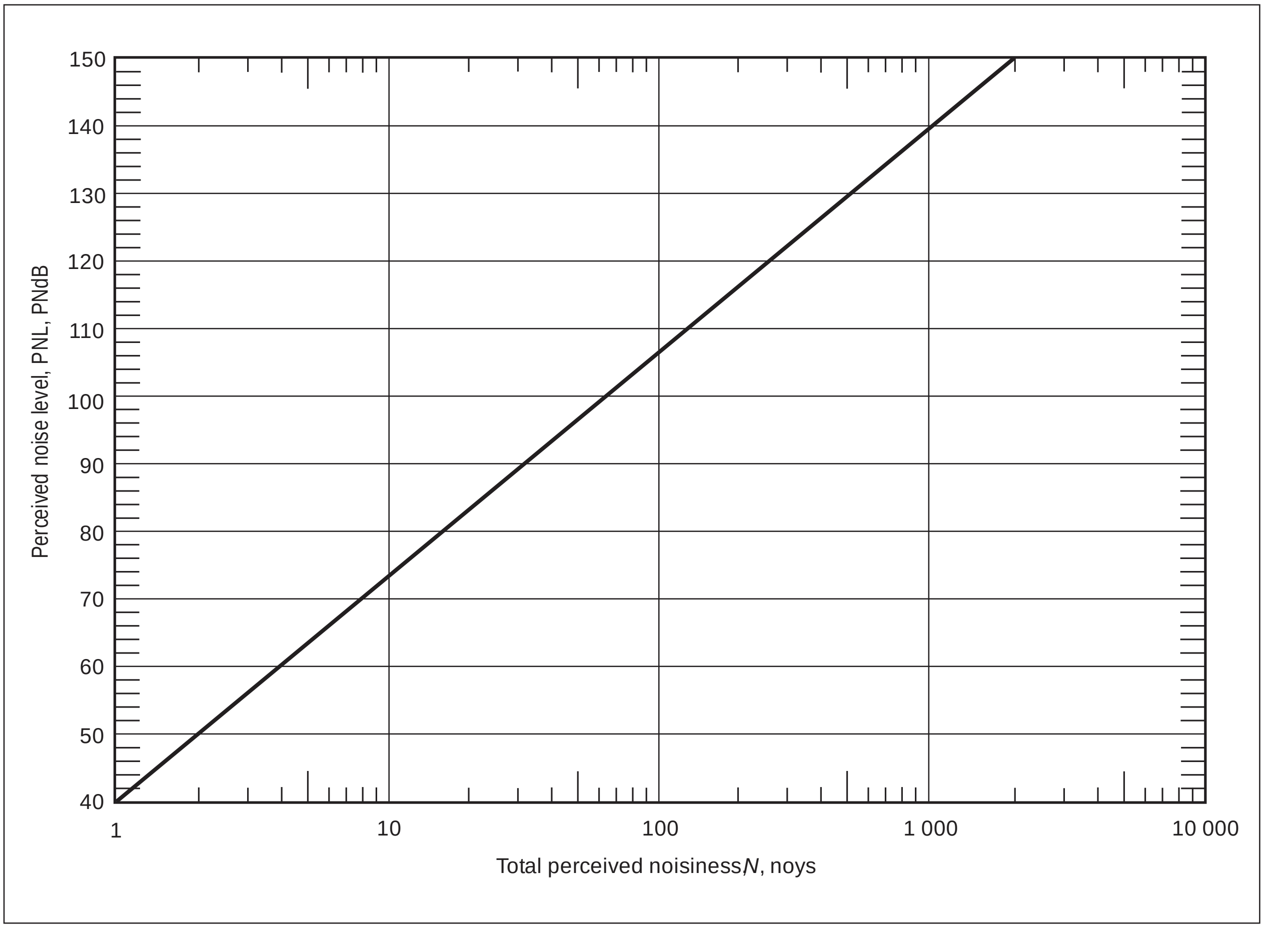


Figure 3-4. Perceived noise level as a function of total perceived noisiness

Chapter 4

GUIDELINES FOR SUBSONIC JET AEROPLANES, PROPELLER-DRIVEN AEROPLANES OVER 8 618 KG, HELICOPTERS AND TILT-ROTORS EVALUATED UNDER ANNEX 16, VOLUME I, APPENDIX 2

4.1 EXPLANATORY INFORMATION

4.1.1 Noise measurements

See 3.1 for technical procedures generally applicable for noise certification tests of all aircraft types including those evaluated under the provisions of Appendix 2 of the Annex. In the following section procedures specific to Appendix 2 are presented.

4.1.2 Noise certification test and measurement conditions

GM A2 2.2.2.4.1 b)
[Ambient air temperature]

1) *Criteria for measuring atmospheric conditions*

Experience has shown that proper measurement of non-reference meteorological conditions and the associated adjustment of noise data for these conditions are crucial to obtaining accurate, consistent and repeatable test results. For aeroplanes, meteorological observations of the temperature and relative humidity are required over the whole sound propagation path from the aircraft to the vicinity of the noise measurement points. For helicopters and tilt-rotors, temperature and relative humidity measurements are required at 10 m (33 ft) in the vicinity of the noise measurement points.

AMC A2 2.2.2.4.1 b)
[Ambient air temperature]

1) *Atmospheric measurements*

Several methods have been approved for the measurement of atmospheric conditions from 10 m (33 ft) above the ground to the altitude of the test aeroplane. Some applicants have used instrumented balloons. Another method consists of a meteorological aeroplane, manned or unmanned, flown in a spiral flight path in the vicinity of the noise measurement points to measure the dry bulb temperature and dew point along the sound propagation path.

AMC A2 2.2.2.2.1
[Calculation of sound attenuation coefficients for the effects of atmospheric absorption]

1) *Basic data*

Measurements of the ambient temperature and relative humidity should be made at 10 m (33 ft) above the ground. The ambient temperature and relative humidity should also be determined with vertical height increments not greater than 30 m (100 ft) over the sound propagation path. All measurements of ambient temperature and relative humidity shall be obtained within 30 minutes of each aeroplane test run.

2) *Determination of the average sound attenuation coefficient*

Table 4-1 is an example of calculation of sound attenuation coefficients in the 3 150 Hz one-third octave band for an aeroplane approach noise certification when multiple layering is not required. Temperature and humidity values obtained from atmospheric soundings performed before and after a series of aeroplane test runs are interpolated to the time of PNLTM.

Table 4-1. Basic data (layering not required)

Height (m)	*Temperature (°C)*	*Relative humidity (%)*	*α (3 150 Hz) (dB/100 m)*
10	14.1	50	2.45
30	13.4	53	2.38
60	12.9	56	2.30
90	12.2	57	2.33
120	11.5	58	2.37
150	11.3	61	2.27

The individual coefficients shown in Table 4-1 are calculated at vertical height increments of 30 m from 10 m to a height of 150 m. The ambient conditions from the ground to 10 m are assumed to be those measured at 10 m.

The individual sound attenuation coefficients for the 3 150 Hz one-third octave band shown in Table 4-1 vary by less than 0.5 dB/100 m relative to the value determined at 10 m (33 ft). In this case the coefficient to be used for adjustment of sound pressure levels from test to reference conditions is the average of the coefficients at 10 m (33 ft) and at the height of the aeroplane at the time of PNLTM.

For this example, the height of the test aeroplane at the time of PNLTM is 125 m. The associated attenuation coefficient is calculated by linear interpolation as follows:

$$y = y_a + \frac{(x - x_a)\times(y_b - y_a)}{(x_b - x_a)}$$

$$\alpha(3\,150)_{125\text{ m}} = 2.37 + \frac{(125-120)\times(2.27-2.37)}{(150-120)}$$

$$\alpha(3\,150)_{125\text{ m}} = 2.35 \text{ dB/100 m.}$$

Then the average attenuation coefficient for the 3 150 Hz one-third octave band used for adjustment of the aeroplane sound pressure levels is calculated as follows:

$$\overline{\alpha(3150)} = \frac{\alpha(3\,150)_{10\text{ m}} + \alpha(3\,150)_{125\text{ m}}}{2}$$

$$\overline{\alpha(3150)} = \frac{2.45 + 2.35}{2}$$

$$\overline{\alpha(3150)} = 2.40 \text{ dB/100 m.}$$

The coefficients for the other one-third octave bands are determined in a similar manner. These average coefficients are then used in the adjustment of aeroplane SPLs to reference conditions. The same general procedure would be used if no layering was required for determining the average coefficients during flyover and lateral noise certification measurements.

3) *Determination of the cumulative sound attenuation coefficients*

Table 4-2 is an example of calculation of sound attenuation coefficients in the 3 150 Hz one-third octave band for an aeroplane flyover noise certification when multiple layering is required. Temperature and humidity values obtained from atmospheric soundings performed before and after a series of aeroplane test runs are interpolated to the time of PNLTM.

Table 4-2. Basic data (layering required)

Height (m)	*Temperature (°C)*	*Relative humidity (%)*	*α (3 150 Hz) (dB/100 m)*
10	7.2	80	2.09
30	7.2	75	2.23
60	8.9	73	2.11
90	10.0	67	2.19
120	10.6	63	2.27
150	10.6	62	2.31
180	10.6	61	2.34
210	10.6	59	2.43
240	11.1	55	2.57
270	11.7	53	2.59
300	11.7	51	2.70
330	11.1	51	2.79
360	11.1	50	2.84
390	11.1	47	3.04
420	11.1	46	3.10

The individual coefficients shown in Table 4-2 are calculated at vertical height increments of 30 m from 10 m to a height of 420 m. The ambient conditions from the ground to 10 m are assumed to be those measured at 10 m.

The individual sound attenuation coefficients for the 3 150 Hz one-third octave band shown in Table 4-2 vary by more than 0.5 dB/100 m. In this case the coefficient to be used for adjustment of sound pressure levels from test to reference conditions is the cumulative sound attenuation from the ground to the height of the aeroplane at the time of PNLTM.

In the absence of extreme or anomalous conditions (e.g. large variations in, or inversions of, temperature and/or humidity), which will generally be the case, it is acceptable, subject to the approval by the certificating authority, to determine the cumulative sound attenuation coefficients for each one-third octave band from a simple average of the coefficients at the boundaries of each layer.

Where extreme or anomalous conditions are present (e.g. large variations in, or inversions of, temperature and/or humidity) the cumulative sound attenuation coefficients for each one-third octave band should be determined by apportioning the sound attenuation coefficients for each layer. Table 4-3 illustrates an example of such a method.

Table 4-3. Determination of the cumulative sound attenuation

Layer boundaries	*Effective layer depth (m)*	*Effective layer depth proportion (%)*	*Sound attenuation coefficients, α (3 150 Hz) (dB/100 m)*	*Average layer sound attenuation coefficients, α (3 150 Hz) (dB/100 m)*	*Apportioned sound attenuation coefficients, α (3 150 Hz) (dB/100 m)*
0–30	28.8	7.03	2.09–2.23	2.16	0.1518
30–60	30.0	7.32	2.23–2.11	2.17	0.1589
60–90	30.0	7.32	2.11–2.19	2.15	0.1574
90–120	30.0	7.32	2.19–2.27	2.23	0.1633
120–150	30.0	7.32	2.27–2.31	2.29	0.1676
150–180	30.0	7.32	2.31–2.34	2.32	0.1698
180–210	30.0	7.32	2.34–2.43	2.39	0.1750
210–240	30.0	7.32	2.43–2.57	2.50	0.1830
240–270	30.0	7.32	2.57–2.59	2.58	0.1889
270–300	30.0	7.32	2.59–2.70	2.65	0.1940
300–330	30.0	7.32	2.70–2.79	2.74	0.2006
330–360	30.0	7.32	2.79–2.84	2.82	0.2064
360–390	30.0	7.32	2.84–3.04	2.94	0.2152
390–411	21.0	5.12	3.04–3.08	3.06	0.1568
				Cumulative sound attenuation coefficient, α (3 150 Hz) (dB/100 m):	**2.49**

The atmosphere is first divided into layers from the ground to the aeroplane height. For this example the height of the aeroplane at the time of PNLTM is 411 m.

The sound attenuation coefficient at the height of the test aeroplane is calculated by linear interpolation of the sound attenuation coefficients at the upper and lower boundaries of the uppermost layer.

The effective layer depth is determined as follows: for all layers between the aeroplane and the microphone, except the lowest layer containing the microphone and the uppermost layer containing the aeroplane, the effective layer depth is the full 30 m; for the lowest layer containing the microphone, the effective layer depth is 30 m minus the 1.2 m height of the microphone; for the uppermost layer containing the aeroplane, the effective layer depth is the height of the aeroplane minus the height of the lower boundary of the layer.

The effective layer depth proportion for each layer is determined as the ratio of that layer’s effective depth relative to the total vertical component of the sound propagation distance from the microphone to the height of the aeroplane at the time of PNLTM.

The average sound attenuation coefficient for each layer is obtained by averaging the coefficients at the upper and lower boundaries of the layer.

The apportioned sound attenuation coefficient for each layer is obtained by multiplying the average layer sound attenuation coefficient by the effective layer depth proportion.

The summation of all apportioned sound attenuation coefficients results in the cumulative sound attenuation coefficient. In this example the cumulative coefficient is calculated for the 3 150 Hz one-third octave band. The same general procedure would be used to obtain the cumulative sound attenuation coefficient for each one-third octave band. These coefficients are then used in the adjustment of aeroplane SPLs to reference conditions.

AMC A2 2.2.2.4.1 e) f) g) h)
[Wind speed]

1) *Real-time crosswind component measurements*

Applicants are advised to provide approved real-time crosswind component measurement systems such that the crosswind component speeds can be verified after each aircraft test run. When the applicant uses a wind measurement system that is remotely located and not readily accessible, such as chart recorders that simultaneously and independently measure and record wind speed and direction, it may not be practical to determine the real-time crosswind component for each test run. For aeroplanes, if the applicant does not provide an acceptable real-time crosswind component measurement system, the 5.1 m/s (10 kt) maximum crosswind component and the 3.6 m/s (7 kt) average crosswind component become the maximum wind limitations regardless of wind direction.

GM A2 2.2.2.4.1 i)
[Anomalous meteorological conditions]

1) *Anomalous winds*

For aeroplanes, compliance of measured wind speeds with the requirements of 2.2.2.4.1 e) of Appendix 2 of the Annex may not be sufficient to ensure that the wind speeds at the aeroplane height or along the sound propagation path are not excessive. Such conditions may exist as a steady headwind, tailwind or crosswind, or as a wind from varying directions with increasing height. Anomalous winds may affect the handling characteristics of an aircraft during the noise duration. They also may affect the transmitted noise. Anomalous winds include not only gusts and turbulent winds, but also wind shear, strong vertical winds, and high crosswinds at the aircraft height and along the sound propagation path. An applicant may be required to measure winds aloft and provide the certificating authority with the information. Acceptability of the wind conditions over the propagation path will be determined by the certificating authority (see 2.2.2.4.1 f) of Appendix 2 of the Annex).

2) *Winds aloft measurement*

Modern INS and DGPS can provide on-board aircraft data that can be used to quantify winds aloft. The measurement of winds aloft can further be processed to provide a permanent record of wind speed and direction.

3) *Effects of wind on aeroplane control*

Certificating authorities have permitted a ±20 per cent tolerance in overhead test height and a ±10° lateral tolerance relative to the extended runway centre line. If the flight crew cannot fly within the pre-test-approved flight path tolerance limits, or experiences major variations in airspeed, or the aeroplane crabs or yaws significantly during the flight, adverse or anomalous wind conditions aloft are often the cause.

4) *Effects of wind on helicopter and tilt-rotor control*

If the test helicopter or tilt-rotor cannot be flown within the pre-test-approved flight path tolerance limits, or experiences major variations in airspeed, or the aircraft yaws or sideslips excessively during the flight, adverse or anomalous wind conditions aloft are often the cause. Normally such issues arise only with gusty wind conditions, high crosswinds or in the presence of strong thermals.

AMC A2 2.2.2.4.1 i)
[Anomalous meteorological conditions]

1) *Flight path*

The flight crew should observe and record any occurrence where conditions aloft cause difficulty in maintaining the flight path or airspeeds, or when rough air in general makes the flight unacceptable.

In the context of determining whether such conditions are present for aeroplanes, 3.7.7 of Chapter 3 of the Annex specifies that "for take-off, lateral, and approach conditions, the variation in instantaneous IAS of the aeroplane must be maintained within ±3 per cent of the average airspeed between the 10 dB-down points. This shall be determined by reference to the pilot's airspeed indicator. However, when the instantaneous IAS varies from the average airspeed over the 10 dB-down points by more than ±5.5 km/h (±3 kt), and this is judged by the certificating authority representative on the flight deck to be due to atmospheric turbulence, then the flight so affected shall be rejected for noise certification purposes."

GM A2 2.2.2.2.1
[Time of meteorological measurements]

1) *Upper atmospheric condition measurements*

Atmospheric conditions affect sound propagation. Therefore, measurements of temperature and relative humidity shall be made before and after each aircraft test run, at least one of which shall be made within 30 minutes of the test run. To avoid the possibility that the meteorological conditions might change significantly over time, both measurements shall be representative of the prevailing conditions during the test run. The measurements shall be made using an approved method at 10 m (33 ft) above the ground surface and, for aeroplanes only, from 10 m (33 ft) above the ground surface to the aeroplane test height at time of PNLTM. These measurements shall be obtained and validated throughout the test period to ensure acceptable meteorological data for the noise data evaluation process.

AMC A2 2.2.2.2.1
[Time of meteorological measurements]

1) *Atmospheric measurements*

Applicants should consider the maximum height that will be attained within the next 60 minutes, or less, of aeroplane test runs to ensure that adequate upper atmospheric measurements are acquired. Interpolations of atmospheric data for all test runs are made to the aeroplane height at the time of PNLTM. To have sufficient meteorological data to perform the interpolation to the actual time of each test run, the first meteorological measurement flight of the day should be made not earlier than 30 minutes before the first test run, and the last meteorological measurement flight of the day should be made not later than 30 minutes after the last test run flight of the day.

2) *Atmospheric data interpolation*

The temperature and relative humidity data at the actual time of the test run shall be interpolated over time and height, as necessary, from the measured meteorological data. The interpolation time of the test run may be taken to be either the time the aircraft flew overhead or abeam the noise measurement point, or the time of PNLTM.

GM A2 2.3.1
[Aircraft position measurement]

1) *Independent aircraft position determination*

The certificating authority will approve only those aircraft position and height indicating and recording systems that are independent from the direct aircraft flight path indicating systems. The data from such independent systems should be recorded to produce a time-coordinated permanent record of each test.

The independent system restriction does not prohibit use of real-time flight guidance systems (e.g. CDI or GDI) on-board the aircraft to assist the flight crew during noise certification tests. Systems such as microwave space position systems, INS, precision distance measuring unit (DMU) and DGPS can also provide guidance to the flight crew by providing the direct, real-time aircraft position relative to the extended runway centre line.

GM A2 2.3.2
[TSPI measurement system characteristics]

1) *Measurement system synchronization*

Approved aircraft position and height measurement systems shall be time-synchronized with the noise and meteorological measurement systems. The time synchronization between noise measurements and aircraft position should be precise. A common time base should be used to synchronize noise, aircraft tracking and meteorological measurements (see GM A2 2.3.2 3) for details).

TSPI should be determined at intervals no greater than one-half second throughout the sound-measuring period (i.e. within 10 dB of PNLTM) by an approved method that is independent from systems installed aboard, and normally used to control, the aircraft. During processing, measured TSPI data shall be interpolated over time to the time of sound emission of each one-half second noise data record within the 10 dB-down period. The time associated with each one-half second record is 0.75 seconds before the end of each 2-second exponential averaging period (see 3.7.6 of Appendix 2 of the Annex).

Although the simplified procedure requires adjustment of only the (PNLT) maximum record to the reference track, emission coordinates should be determined for each one-half second record for use in background noise adjustment procedures and/or for determination of incidence-dependent free-field microphone and windscreen adjustments.

2) *Measurement system component approval*

Some off-the-shelf TSPI equipment may require software enhancement to accommodate the specific installation. Each applicant should submit information to the certificating authority about the software used. The certificating authority will determine whether the software yields results that satisfy the Annex Standards. All TSPI equipment and software should be demonstrated to, and approved by, the certificating authority to ensure the system's operational accuracy.

3) *Methods of time synchronization*

Special care should be taken to properly synchronize noise data recordings with TSPI data (see 3.4, for details of specific methods).

GM A2 2.3.3
[Aircraft performance]

1) *Aircraft and engine performance parameters*

Examples of parameters needed for measurement of aircraft and engine performance include aircraft height, climb angle, airspeed, gross mass, flap position, landing gear position, engine thrust (power) setting parameters (e.g. compressor rotor speed, engine pressure ratio, exhaust gas temperature), and aircraft accessory condition (e.g. air conditioning and auxiliary power unit (APU) "on" or "off"). Any other parameters that may affect measurement or adjustment of noise data and/or aircraft or engine performance should also be recorded throughout the 10 dB-down period (e.g. the status of surge bleed valves (SBV) and the centre of gravity (CG) position).

AMC A2 2.3.3
[Aircraft performance]

1) *Aircraft performance measurements*

Calibrated instrumentation is required to determine aircraft performance. Adequate aircraft and engine parameters are to be recorded during all certification testing to ensure that aircraft performance can be accurately determined. For example, for transport aeroplanes this may necessitate measurement and recording of flap position, landing gear position, speed brake position, APU operation, and normal engine thrust (power) setting and associated flight parameters. Determination and recording of adequate information enables validation of the test configuration and adjustment of performance and engine performance from test conditions to reference conditions specified in 3.6 of Chapter 3 of the Annex.

2) *Recorder sampling rate*

The measurements of aircraft position, airspeed, performance and engine performance parameters are to be recorded at an approved sampling rate sufficient to permit adjustments from test to reference conditions throughout the 10 dB-down period. An acceptable recording sampling rate is two to five samples per second.

4.1.3 Measurement of aircraft noise received on the ground

GM A2 3.2
[Environmental specifications]

1) *Measurement system performance*

The environmental conditions for specifying the performance of a measurement system are specified in 3.2 of Appendix 2 of the Annex.

GM A2 3.3.1
[Measurement system specifications]

1) *Measurement system criteria*

The specifications for a measurement system allow flexibility in the procurement of measurement system components by the applicant. While on-site EPNL analysis may be useful for estimation of recording levels or for other diagnostic purposes, a true acoustical analysis requires that time-pressure data be recorded in the field. This will allow for later reanalysis or auditing of acoustical data. A recording also facilitates later offline processing of acoustic data, including application of adjustments for items such as system frequency response, microphone pressure response and analyser bandwidth error. Recording simplifies synchronization with other pertinent data, such as tracking and meteorological measurements. Such synchronization is necessary for proper application of many of the required adjustments to noise data, such as adjustments for microphone free-field response, windscreen incidence-dependent insertion loss, the influence of ambient noise, high altitude jet noise effects, non-reference flight performance, and non-reference meteorological conditions.

2) *Approval of measurement system*

The approval by the certificating authority should be obtained for systems used for measurement, recording and analysis of aircraft noise. Most of the currently available system components that are appropriate for aircraft noise certification have already been approved, but implementation of new technology and variants or upgrades of existing components may require approval by the certificating authority. Of special concern is the potential for a digital component's functionality to change as a result of firmware or operating system upgrades or modifications. Applicants should be aware that approval of a particular component might be version-dependent.

AMC A2 3.5.2

[Microphone orientation]

1) *Microphone orientation*

Figure 4-1 shows the orientations relative to a microphone sensing unit for grazing and normal incidence. For microphones located directly under the flight path, an orientation angle of 90° from vertical is appropriate regardless of target height. For noise measurements to the side of the flight path, applicants may wish to reorient the microphones for grazing incidence for each target height in order to maintain substantially grazing incidence throughout the 10 dB-down periods. In many cases, this reorientation can eliminate the need to apply data adjustments for varying incidence, since the incidence angles will be more likely to be contained within ±30º of grazing incidence. Figure 4-1 provides illustrations of microphones positioned for grazing incidence under the flight path and to the side of the flight path of an aeroplane.

GM A2 3.5.4
[Microphone specifications]

1) *Microphone specifications*

Table A2-1 of Appendix 2 of the Annex specifies the maximum permitted differences between the free-field sensitivity of a microphone at normal incidence and the free-field sensitivity at specified sound incidence angles for sinusoidal sound waves at each one-third octave band nominal midband frequency over the range of 50 Hz to 10 kHz. These differences are larger at higher frequencies, allowing for the effect of the microphone body in a free-field environment.

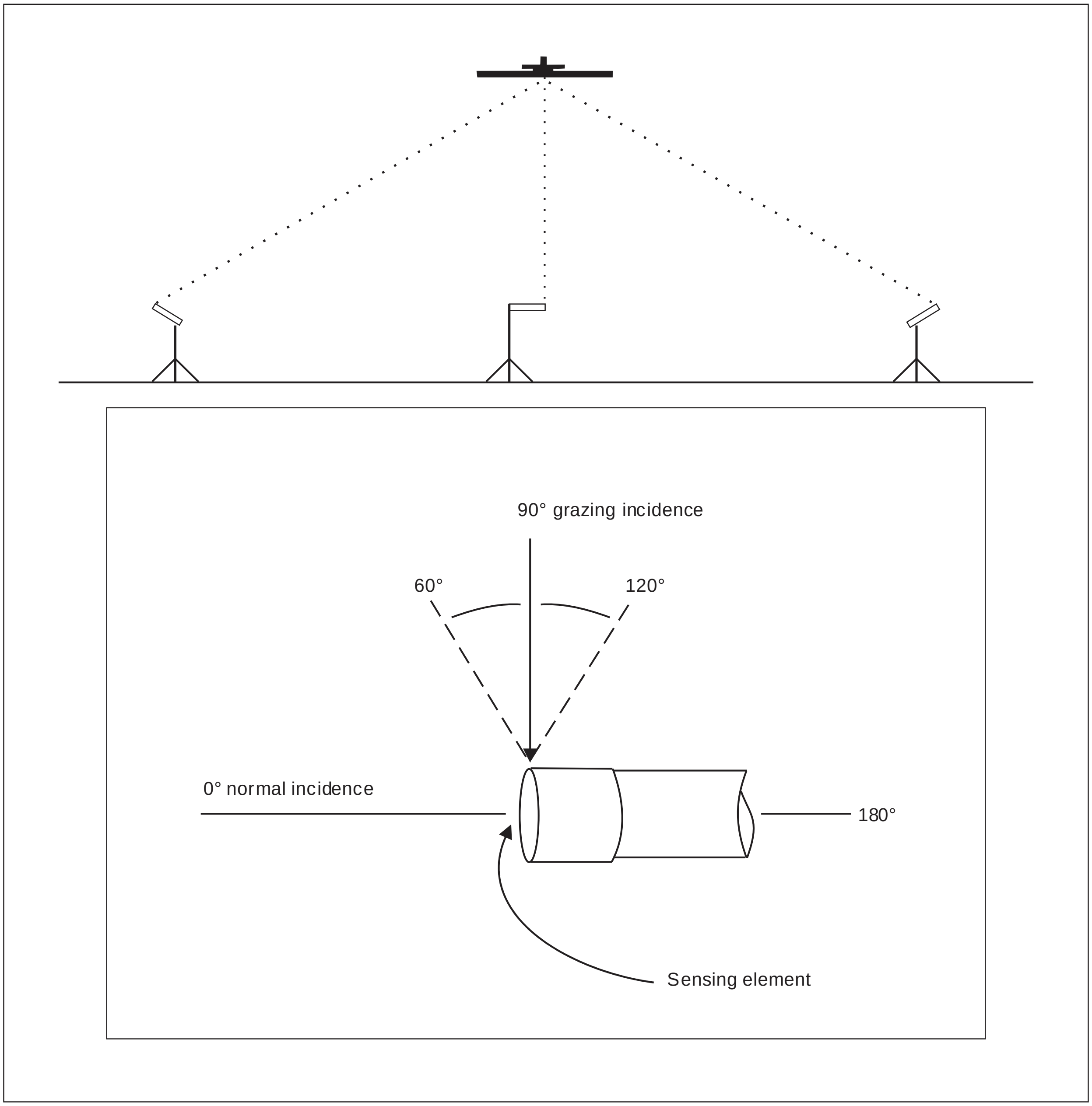


Figure 4-1. Illustration of sound incidence angles on a microphone

2) *Microphone characteristics*

The specifications of Table A2-1 of Appendix 2 of the Annex are based on the performance characteristics of typical one-half inch condenser microphones designed for nearly uniform frequency response at grazing incidence (see Figure 4-1). Other microphones may be used, provided they meet the specified performance requirements. For example, prepolarized (i.e. electret condenser) free-field microphones greatly minimize the possibility of arcing in humid environments and do not require an external polarization voltage.

Although many of these microphones are intended primarily for use in normal-incidence free-field applications, they can be used in aircraft noise certification testing if their performance at grazing incidence meets the requirements of 3.5 of Appendix 2 of the Annex.

GM A2 3.6.1
[Recorder specifications]

1) *Recorder types*

An applicant has a choice of recorder types that will satisfy the requirement for recording "the complete acoustic signal" during certification testing. In addition to a magnetic tape recorder, other means of attaining a "true" acoustic recording include digital audiotape (DAT), recordable compact disc (CD-R) and direct-to-hard-disk recording. The applicant should be aware that systems that use data compression techniques that result in substantial data loss, such as mini-disc (MD) or digital compact cassette (DCC), are not acceptable.

AMC A2 3.6.1
[Recorder specifications]

1) *Frequency range for recordings*

The time-varying waveform produced by the microphone response to noise signals during certification tests should be recorded. If there are questions about the data observed during the tests, the recording can be replayed, multiple times if necessary, to verify the results. Recorded data, whether digital or analogue in nature, should allow reproduction and reprocessing of an analogue signal over the frequency range of 40 Hz to 12.6 kHz. A dynamic range of at least 60 dB is recommended.

Many typical instrumentation DAT recorders feature a nominal 10 kHz bandwidth operating mode in which the attenuating response of the anti-aliasing filter intrudes within the 10 kHz one-third octave passband. In such cases, the recorder should be operated in a nominal 20 kHz bandwidth mode, which may reduce the number of available channels or the duration of available time per tape.

Note.— Although the one-third octave bands of interest are those with nominal centre frequencies of 50 Hz through 10 kHz, to ensure that the entire actual bandwidth of the uppermost and lowermost bands is included, the centre frequencies of the one-third octave bands immediately outside this range are specified.

2) *Digital recording levels*

The overload characteristic of a digital system is determined primarily by the limits of the analogue-to-digital conversion. Since such an overload condition is characterized by an abrupt, catastrophic type of distortion, the level range should be set so that the anticipated maximum signal level is at least 10 dB, and preferably 20 dB, below the upper boundary of the linear operating range.

3) *Dynamic range limits for digital recorders*

The lower limit of a digital recording system's usable dynamic range is more often determined by amplitude non-linearity due to "quantization error", rather than by the presence of a noise floor. Digital devices such as recorders or analysers that are to be used for aircraft noise certification purposes should be tested to determine the extent of such non-linearity.

4) *16-bit quantization systems*

The theoretical dynamic range of such a system is usually assumed to be near 96 dB (i.e. $20 \times \log (2^{16})$). At the lower limit of this range, there is a potential for a 6-dB error in the digitized signal versus the analogue input signal that it represents. Reference 2 imposes a ±0.4 dB limit on acceptable linearity error in the reference level range and ±0.5 dB for a linear operating range of at least 50 dB. As amplitude levels are increased above the lower quantization limit, the linearity error is reduced. If the guidance for setting the level range is followed, the usable dynamic range is further decreased. Significant improvement of amplitude linearity can be obtained via the implementation of techniques such as oversampling and dithering. Therefore, testing shall be performed to determine the actual limits for each digital recording system. Note that assumptions based on experience with analogue systems do not always apply.

AMC A2 3.6.2
[Pre-emphasis]

1) *Pre-emphasis systems*

Use of pre-emphasis systems will be allowed only if the system also employs complementary de-emphasis. Attempts to compensate for the effects of a pre-emphasis filter by applying one-third octave band de-emphasis adjustments, either numerically to analysed data via a pink noise adjustment, or on a band-by-band basis using separate gain stages for each one-third octave band filter, are not allowed. In addition, use of a pre-emphasis/de-emphasis system will require testing and documentation of all filters and gain stages involved to ensure that any errors are quantified and minimized and that the system performs predictably and reliably.

AMC A2 3.6.9
[Attenuator specifications]

1) *Attenuator specifications*

Attenuator specifications allow for the use of switchable voltage input range settings, now commonplace on DAT recorders, as controllable attenuation steps for gain-setting purposes. In all cases, attenuators should have fixed repeatable steps. Any devices in the measurement system that use vernier or continuously-adjustable gain controls should also have some demonstrable means of being fixed, or locked at a specific setting, to eliminate non-traceable gain errors.

GM A2 3.7.2
[Linear integrating analyser specifications]

1) *Externally controlled linear-integrating analysers*

In cases where a computer or other external device is used to control and/or communicate with an analyser performing linear integration, extra care should be taken to ensure that the integration period requirements are met. Some analysers from major manufacturers have required a factory modification in order to provide an integration time within 5 ms of the specified 500-ms integration period.

GM A2 3.7.3
[Analyser performance specifications]

1) *Analyser specifications*

Reference 3 specifies the electrical performance requirements of one-third octave band filters, including tolerances for the attenuation in the transition bands (i.e. "skirts") adjacent to the one-third octave passbands. Most digital one-third octave band analysis systems offer only hardwired filtering algorithms that emulate the response of a traditional third-order analysis filter having a maximally flat passband. However, some analysis systems allow the selection of other filtering algorithms that might not provide equivalent performance. Applicants should demonstrate the effects that alternate filter design response characteristics might have on noise certification EPNL values.

2) *Determination of bandwidth error adjustments*

The manufacturer can establish the geometric centre frequencies of one-third octave band filters using either Base 2 or Base 10 systems. While the use of either method results in frequencies close to the nominal centre frequencies referred to in Table A2-3 of Appendix 2 of the Annex, it is important to note which system is used so that the bandwidth error adjustment can be properly determined. Use of test frequencies calculated by a different base-number system than that for which the analyser was designed can result in erroneous values for these adjustments.

AMC A2 3.9.3
[Microphone incidence adjustments]

1) *Applications of adjustments for incidence*

When using microphones whose frequency response is nearly flat at grazing incidence, and when the angles of incidence of sound emitted from the aircraft are within ±30° of grazing incidence, a single set of data adjustments for free-field response and windscreen insertion loss, based on grazing incidence, is considered sufficient to account for incidence effects. When it is impractical to orient the microphone properly to maintain grazing incidence, provided that a continuous record of TSPI is available, free-field and windscreen insertion-loss incidence data adjustments can be applied to the noise data on a spectral-record by spectral-record basis. These adjustments are obtained by calculating the angle of incidence for each record, using the point of time that characterizes the 2-second averaging period (see 3.7.6 of Appendix 2 of the Annex) and determining the aircraft's emission coordinates and angle of incidence for the sound measured at that time.

GM A2 3.9.4
[Pink noise specifications]

1) *Pink noise*

Pink noise contains equal energy in each octave band or fractional octave band (e.g. the octave from 100 Hz to 200 Hz contains the same amount of energy as the octave from 1 kHz to 2 kHz, although for the lower-frequency octave, it is distributed over a frequency range 10 times narrower).

2) *Pink noise usage*

Because of the dynamic nature of the pink noise signal, longer samples produce statistically better measurements. A minimum duration of 30 seconds of pink noise should be recorded.

AMC A2 3.9.5
[Measurement system field calibration]

1) *Measurement system field calibration (all components of the measurement system, except microphones)*

All components of the measurement system, except microphones, should be tested while deployed in the field, using pink noise at a level within 5 dB of the calibration level (see 3.9.5 of Appendix 2 of the Annex). The signal should be recorded for a duration of at least 30 seconds so that one-third octave band system frequency response adjustments can be determined and applied during analysis. The pink noise generator should be calibrated within 6 months of the measurement and is acceptable for certification use only if its output in each one-third octave band does not change by more than 0.2 dB between calibrations.

AMC A2 3.9.6
[Windscreen loss adjustments]

1) *Determination of windscreen data adjustments*

The physical condition of a windscreen can significantly affect its performance, and manufacturer-provided windscreen data adjustments for insertion loss are valid only for new, or clean, dry windscreens. For these adjustments, a single set of values based upon windscreen insertion loss tests at grazing incidence may be used when the angles of incidence of sound emitted from an aircraft are within +30° of grazing incidence. For other cases, the windscreen insertion loss adjustments should be determined and applied on the basis of intervals between angles tested not exceeding 30°.

When the windscreen data adjustments provided by the manufacturer are presented in the form of curves, care should be taken to include the insertion loss throughout each one-third octave band, rather than just at the nominal midband frequency. Windscreen insertion loss can vary substantially within the frequency range of a single band and shall be averaged or faired to more accurately correct one-third octave band data for the presence of the windscreen. Windscreen data adjustments may also be obtained by free-field calibration in an anechoic chamber.

AMC A2 3.9.8
[Field acoustical calibrations]

1) *Field acoustical calibrations*

All components of the system, excluding the windscreen, should be in place at this time, including cables, attenuators, gain and signal-conditioning amplifiers, filters (including pre-emphasis) and power supplies. During calibration, attenuators and gain stages should be set to prevent overload and to maintain the calibration signal level on the reference level range within the limits specified in 3.6.6 of Appendix 2 of the Annex. If any switchable filters that could affect the calibration signal are utilized during measurements, then calibrations should be performed both with and without these filters enabled. Components of the electrical system should not be added, removed or replaced without re-calibrating the entire system immediately before and after each change.

AMC A2 3.10.1
[Measurement system background noise]

1) *Measurement system noise*

Since measurement system noise can add energy to measured aircraft noise levels, the background noise measurement described in 3.10.1 of Appendix 2 of the Annex should be made with all gain stages and attenuators set as they would be used during the aircraft noise certification measurements. If it is expected that multiple settings will be required during the measurements, background noise data should be collected at each of these settings. Care should be taken to ensure that the background noise is truly representative of that present during the aircraft noise certification tests.

2) *Mean background noise assessments*

At least 30 seconds of background noise data shall be time-averaged to determine the mean level for each one-third octave band. The PNL value for this averaged spectrum should then be calculated using the procedures defined in 4.1.3 a) of Appendix 2 of the Annex. The aircraft noise level data should also be analysed and PNL values calculated for each spectral record. The maximum aircraft PNL value should be at least 20 dB above the PNL of the averaged background noise spectrum for the data to be considered acceptable.

4.1.4 Calculation of EPNL from measured data

GM A2 4.2
[Instantaneous sound pressure levels]

1) *Instantaneous sound pressure levels*

For the purposes of this procedure, “instantaneous” sound pressure levels are considered to be one-third octave band sound pressure levels for each one-half second record obtained using a continuous exponential averaging process, as described in 3.7.5 of Appendix 2 of the Annex, or its equivalent.

AMC A2 4.3.1
[Tone correction calculation]

1) Data precision for tone correction computation

Prior to Step 1, it is recommended that all one-third octave band sound pressure levels be temporarily rounded to 0.1 dB resolution. The tone correction procedure presented here includes several steps that utilize decibel level criteria to characterize the significance of tonal content. These criteria can become artificially sensitive to small variations in level if a resolution finer than 0.1 dB is used in the computations.

AMC A2 4.3.1 (Steps 4, 5)
[Adjustments relating to background noise]

1) *Data adjustments for background noise*

When the technical procedure presented in 3.6.3.2 is used for adjustment for the effects of background noise, Steps 4 and 5 of this tone correction procedure should be modified as follows:

— *Step 4.* The LGB should be used in place of the highest frequency band (i = 24); and

— *Step 5.* A new slope, $s'(25,k)$, should be calculated for the band beyond LGB as described for an imaginary 25th band. This slope should be used in place of the slope derived from the actual level of the band beyond LGB.

AMC A2 4.3.1 (Step 10)
[Data resolution after tone correction calculation]

1) *Data precision (after calculation of tone correction factor)*

At this point, the original sound pressure level resolution of 0.01 dB should be restored. Although the required precision of reported EPNL is 0.1 dB, all other intermediate calculations external to the tone correction process should maintain a precision of at least 0.01 dB.

2) *Identification of pseudo-tones*

Section 4.3.2.2 presents guidance material on methods for identifying pseudo-tones. Note that the use of ground plane or 10 m (33 ft) microphones is supplemental to the required 1.2 m (4 ft) microphones and is allowed only for identification of frequency bands within which pseudo-tones might occur and not for the determination of aircraft certification noise levels.

3) *Tone correction factor adjustment*

When tone correction factors result from false or fictitious tones, recalculation is allowed using revised sound pressure level values, based on narrow-band analysis, of the smoothed spectral levels obtained in Step 7. Once the levels have been revised, the tone correction factor should be recomputed for the revised one-third octave band spectrum. This recomputed maximum tone correction factor should be applied, even if it occurs at or near the band associated with an artificial tone, and approval by the certificating authority should be obtained for the methodology used.

GM A2 4.4.2
[Bandsharing adjustment]

1) *Bandsharing adjustment concept*

The one-third octave band filtering process specified for analysis of aircraft noise certification data in 4.3.2 of Appendix 2 of the Annex may allow the tone correction procedure to under-predict a tone correction factor when the frequency of a tone is located at or near the edge of one or more one-third octave bands. To account for this phenomenon, a bandsharing adjustment is computed that takes advantage of the fact that, as a result of the Doppler effect, a tone that is suppressed at PNLTM will probably appear normally in the spectra that occur before or after PNLTM. By averaging the tone correction factors calculated for the spectra within a 2-second period around PNLTM, the tone correction factor that would have occurred at PNLTM if it were not suppressed can be reasonably estimated.

AMC A2 4.4.2
[Calculation of bandsharing adjustment]

1) *Computation of bandsharing adjustment*

Although the Annex refers to identification of the frequency bands in which maximum tone corrections occur for the records near PNLTM, the presence or absence of bandsharing cannot be established merely by observing these frequencies. Even though the maximum tone that occurs in a one-third octave band spectrum may not be related to the band of maximum tone correction in the PNLTM spectrum, a related tone may still be present. Therefore, the average of the tone corrections of all spectra within one second (i.e. five, one-half-second data records) of PNLTM should be used regardless of the bands in which maximum tones are found. If the bandsharing adjustment is believed to result from effects other than bandsharing, the applicant should demonstrate its absence for each event.

2) *Adjustment of PNLTM for bandsharing*

The bandsharing adjustment should be computed before the determination of the 10 dB-down period and should be included in the reported PNLTM and EPNL values for the test condition data.

3) *Application of bandsharing adjustment for simplified procedure*

When the simplified procedure is used to adjust data to reference conditions, the bandsharing adjustment should be applied to the $PNLT_R$ at time of PNLTM before "Δ_1" and $EPNL_R$ are calculated.

4) *Application of bandsharing adjustment for integrated procedure*

When the integrated procedure is used to adjust data to reference conditions, a new bandsharing adjustment should be calculated as in 4.4.2 of Appendix 2 of the Annex. This new bandsharing adjustment uses the average of the tone correction factors of the $PNLTM_R$ spectrum and the two preceding and two succeeding spectra, after adjusting them to reference conditions, and should be applied to the $PNLTM_R$ value prior to identification of the reference condition 10 dB-down points and calculation of $EPNL_R$.

AMC A2 4.5
[Noise duration]

1) *Noise duration (10 dB-down period)*

This period is the portion of the aircraft flyover in which the measured noise level is within 10 dB of PNLTM (i.e. the period to be used for the calculation of EPNL). To ensure an adequate duration of recorded noise, recording systems should be activated, and the aircraft maintaining a stable condition, when the noise level at the first microphone location is estimated to be approximately 20 dB(A) below what is expected to be L_{ASmax}. Care should be taken during use of the flight path intercept method (see 4.2.1.1.1) to ensure that noise levels have fallen 20 dB(A) below L_{ASmax} before flight path go-around procedures are initiated.

Note.— If recorded data do not encompass the entire 10 dB-down period, an EPNL *cannot be calculated from those data, and the event should not be used for aircraft noise certification purposes.*

2) *Identification of the first and last records within the noise duration*

When identifying the records that define the limits of the noise duration, those records having PNLT values closest to the actual value of PNLTM – 10 dB should be used. As a result, the PNLT values for the PNLTM – 10 dB points may not always be greater than or equal to PNLTM – 10 dB.

In order to illustrate the correct identification of the 10 dB-down points, Figure 4-2 provides examples of PNLT time-histories made up of records calculated from measured one-half-second values of SPL in accordance with the procedures specified in 4.5 of Appendix 2. The shaded record k_M represents the record associated with PNLTM. Shaded records k_F and k_L represent, respectively, the first and last 10 dB-down points.

In the first example the PNLT value associated with k_F is greater than PNLTM – 10. The PNLT value associated with k_L is less than PNLTM – 10.

In the second example there are two records after k_M with a value equal to PNLTM – 10. In this case k_L is the last of the two records. The first 10 dB-down point, k_F, is the record closest in value to PNLTM – 10, ignoring any records that precede it with greater values but which are less in value than PNLTM – 10.

Note.— In all cases in the calculation of EPNL, *the contribution of all the records from* k_F *to* k_L *inclusive should be included.*

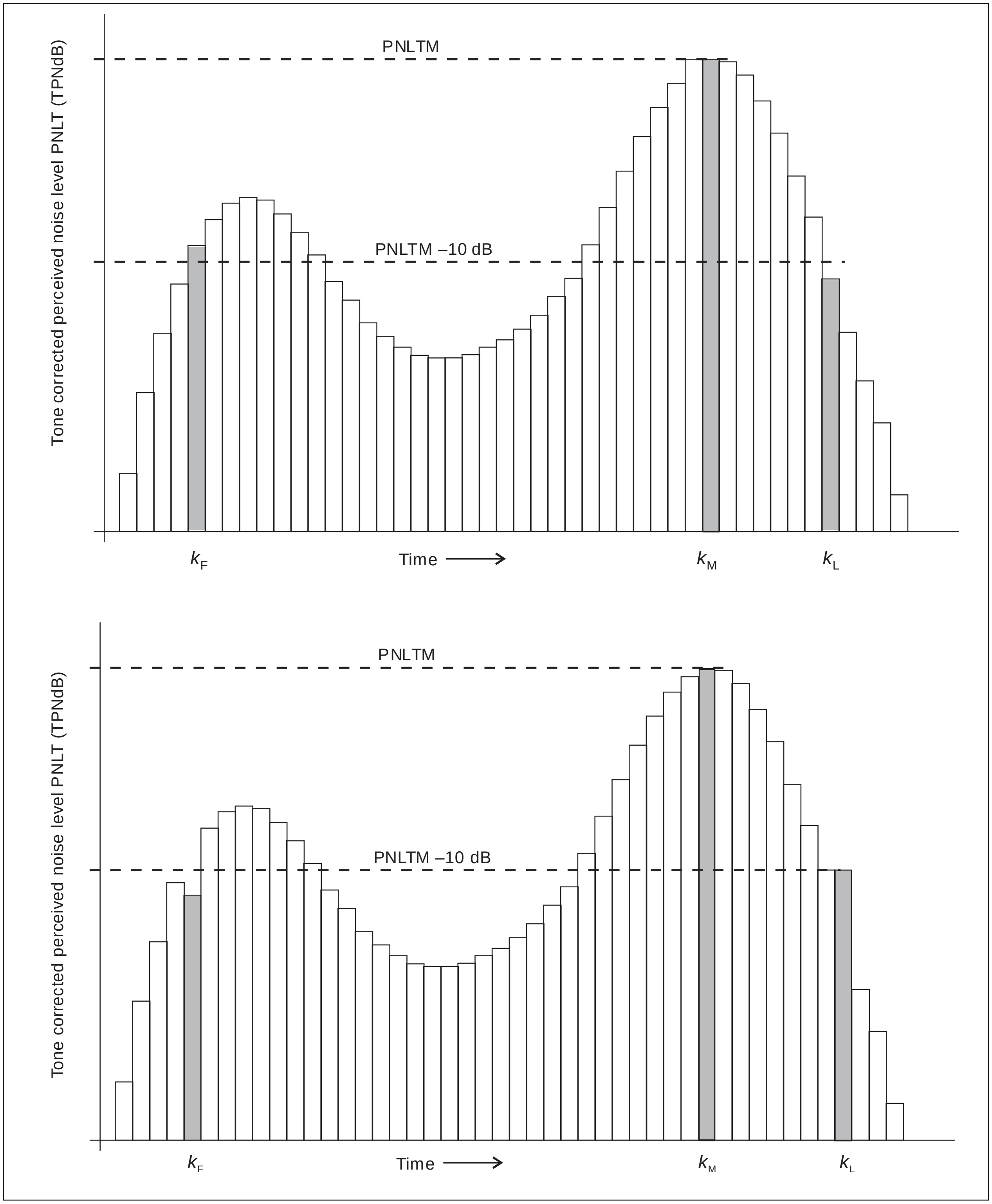


Figure 4-2. Illustrated example of identification of first and last 10 dB-down records

4.1.5 Reporting of data to the certificating authority

GM A2 5.1
[Compliance records]

1) *Compliance records*

For compliance with section 5 of Appendix 2 of the Annex, all data measured during noise certification testing, including time-histories of physical measurements, noise recordings, instrument calibrations, etc., are to be recorded in permanent form and made available to the certificating authority for review, inspection and approval. A common procedure is for the applicant to submit representative samples of test data for each noise measurement point and adjustments to measured data to permit the certificating authority to determine compliance with the Annex. The applicant may either submit the complete test records along with the required data adjustments, or when approved by the certificating authority, the applicant may instead submit samples of test data along with the required data adjustments.

GM A2 5.4
[$\mathrm{EPNL_R}$ average values]

1) *Average $\mathrm{EPNL_R}$ levels when using the NPD equivalent procedure*

For aeroplanes the average value of $\mathrm{EPNL_R}$ from an NPD database (see 4.2.1.1.2.1) is the noise level determined along the regression line through the adjusted data set at the appropriate thrust (power) and distance values, including any other additional adjustments necessary (e.g. adjustment to the aircraft reference speed).

2) *Single test values*

When more than one noise measurement system is used at any one noise measurement point, the resulting noise level is to be the average of the measured noise levels for each noise measurement point. This requirement does not apply to noise levels measured by microphones not required for acquisition of noise certification data.

3) *Valid conditions*

All valid noise measurements are to be included in the confidence interval calculations even when they produce results that are outside the 90 per cent confidence limit of ±1.5 dB. The cause of erratic or possibly invalid noise data may include testing under different temperature and humidity extremes, anomalous winds aloft, changes in noise measurement system components, changes in aircraft hardware, background noise, shift in instrument calibrations, or not testing in accordance with the approved test plan, etc. The certificating authority is to make a determination, during the course of noise certification testing, as to the validity of all noise measurements. A noise measurement may not be excluded from the confidence interval calculations at a later date without approval by the certificating authority. Noise measurements determined in the field to be invalid for any reason may need to be repeated in order to achieve the required minimum number of valid test runs.

AMC A2 5.4
[Calculation of 90 per cent confidence intervals]

1) *Methods for calculating 90 per cent confidence intervals*

Section 3.5, provides confidence interval calculation methods for clustered measurements, regression mean line, static-test-derived NPD curves and analytically derived NPD curves, along with worked examples. Calculation methods for determining 90 per cent confidence interval values for clustered and pooled data sets are presented in 3.5.6.2 and 3.5.6.5.

2) *Retest requirements*

The certificating authority may require an applicant to retest or provide additional test data for any of the three noise measurement points when the reported results indicate:

a) a required measurement is reported to be invalid; or

b) an insufficient number of measurements were conducted by the applicant to determine a suitable data sample; or

c) data scatter indicates that the data are not from a normal population or trend (e.g. a discontinuity due to low power SBV operation); or

d) the 90 per cent confidence interval for a noise measuring condition exceeds the allowable ±1.5 dB; or

e) the test was not conducted in accordance with an approved noise certification compliance demonstration plan.

4.1.6 Nomenclature: symbols and units

(Reserved)

4.1.7 Sound attenuation in air

(Reserved)

4.1.8 Adjustment of helicopter and tilt-rotor flight test results

The objective of a noise certification test is to acquire data for establishing an accurate and reliable definition of a helicopter's or tilt-rotor's noise characteristics. Sections 8.7 of Chapter 8 and 13.7 of Chapter 13 of the Annex establish a range of test conditions and procedures for adjusting measured data to reference conditions.

GM No. 1 A2 8.3
[Adjustments to reference conditions]

1) *Adjustments to reference conditions*

Most noise certification tests are conducted during conditions other than the reference conditions. This includes differences in height, lateral position, airspeed, rotor speed, temperature and relative humidity. Therefore, measured noise data should be adjusted to reference conditions to determine whether compliance with the noise certification limits of Chapter 8 or Chapter 13 of the Annex may be achieved. Both positive and negative adjustments must be applied for the differences between the test and reference conditions. Adjustment procedures and analysis methods should be reviewed and approved by the certificating authority. The certificating authority should ensure that data adjustment and analysis methods that are proposed by applicants satisfy the requirements of the Annex and approved procedures. Any changes, including software revisions, firmware upgrades or instrumentation changes, are subject to the review of the certificating authority before they can be used for noise certification evaluations. Programme validation should be planned and the required information submitted to the certificating authority early in the certification cycle, since the time required for evaluation and approval may vary depending upon the issues encountered.

2) *Non-positive SPLs*

Whenever non-positive one-third octave band aircraft noise levels are obtained, whether as part of the original one-third octave band analysis or as a result of adjustments for background noise, or other approved procedures, their values should be included in all relevant calculations. The practice of "band-dropping", where masked levels are methodically set equal to zero, is not considered to be an acceptable substitute for reconstruction of masked levels as per the background noise adjustment guidance provided in 3.6. For any aircraft noise spectrum subject to adjustment to reference conditions, all one-third octave bands, including those containing masked levels or reconstructed levels, including values less than or equal to zero dB, should be adjusted for differences between test and reference conditions.

3) *Direction of flight considerations*

Since overflights are made in two directions with headwind and tailwind components, the lateral (sideline) microphones will be either "left sideline" or "right sideline" depending on the direction of flight. Hence sideline overflight data need to be sorted by left microphone and right microphone for data adjustments and reporting. Note that sorting by left and right sideline microphone is also appropriate for take-off and approach if more than one direction of flight is used.

It should also be noted that an equal number of overflight test runs with headwind and tailwind components are required. If after analysis the applicant finds that there is at least the required minimum of three measured values in each flight direction, but there are more in one direction than in the other, the applicant then will need approval by the certificating authority as to which are to be used in the determination of the final EPNL value for overflight.

GM No. 2 A2 8.2.1
[Reference data sources]

1) *Manufacturer's data*

Adjustment of noise values from test to reference conditions should be based on approved manufacturer's data. Manufacturer's data should include:

a) reference flight profiles;

b) take-off and overflight engine power settings at reference conditions; and

c) reference airspeeds.

GM A2 8.3.1.2
[Adjustments to measured noise data]

1) *Reference flight path sound emission angle*

In calculating the position of the PNLTM on the reference flight path, the emission (i.e. sound propagation) angle θ relative to the flight test path must be kept the same as for the test flight path. The elevation angle ψ relative to the ground plane is not constrained, and determination and reporting of this angle is not required.

2) *Maximum adjustments*

To prevent excessive adjustments to the measured data, the summation of all the adjustments for differences between the test flight path and the reference flight path for overflight and approach is limited to 2 EPNdB. For take-off the summation of the adjustments is limited to 4 EPNdB of which the sum of Δ_1 and the –7.5 log term from Δ_2 must not exceed 2 EPNdB. The additional allowance for take-off acknowledges that larger differences between the test flight path and reference flight path can occur for this condition as a result of the influence of wind speed on the test flight path. It is recommended, however, that the applicant note that methods discussed in AMC A2 8.1.2.1 can be used to minimize this difference for take-off.

GM A2 8.1.2.1
[Take-off profile]

1) *Reference take-off profile*

Figure 4-3 illustrates the reference take-off profile and an idealized test or measured take-off profile under zero wind conditions. The reference take-off profile is a straight line segment. It starts from a defined point C_r that is 500 m (1 640 ft) from the centre microphone location A and at a height of 20 m (65 ft) above the ground. The reference climb angle γ_R of the straight line path will depend on the certificated best rate of climb and V_Y at the reference conditions. The reference profile ends at a point I_r which will encompass the 10 dB-down period of the noise measurements.

Note.— For clarity the location of the test and reference PNLTM points, L *and* L_r*, are illustrated at the same position for both the centre line noise measurement point* A *and the starboard lateral (sideline) noise measurement point* S*. Normally however* L*, and hence* L_r*, will be a different position on the test and reference flight paths for each noise measurement point.*

2) *Reference climb angle*

The reference climb angle, γ, is based on the best rate of climb and V_Y airspeed determined from approved manufacturer's data for the take-off performance of the helicopter or tilt-rotor at the reference conditions. In the case of the tilt-rotor, V_Y airspeed is a function of the nacelle angle selected by the applicant for the take-off condition. Since airspeed is defined as being in the direction of the flight path, the climb angle γ is the arcsine of the ratio of best rate of climb to V_Y. On an aircraft that is engine-power-limited at the reference conditions, the best rate of climb has to be calculated from the minimum specification engine(s) performance. On many aircraft the take-off characteristics will be dependent on gearbox torque limit, and this will be typically less than the torque associated with minimum specification engine(s) at the reference conditions. Since all procedures have to be consistent with the airworthiness regulations, the gearbox take-off torque limit should be used to calculate the applicable best rate of climb at the maximum noise certification mass for those aircraft that are performance-limited by the gearbox characteristics at the reference conditions.

AMC No. 1 A2 8.1.2.1
[Take-off test conditions]

1) *Take-off requirements*

The take-off profile is commenced from a level flight at a height of 20 m (65 ft). After reaching position C, take-off power has to be applied to initiate the climb. The take-off power will either be dependent on the gearbox torque limit for take-off or minimum installed engine(s) take-off power torque at the reference conditions at sea level and 25°C (77ºF).

2) *Test airspeed*

The best rate of climb airspeed, V_Y, to be used is that determined from the take-off performance at sea level and 25°C (77°F) during airworthiness certification. This is to be maintained during the complete take-off procedure. To account for test-to-test variation and slight variations during each test run, a tolerance of ±9 km/h (±5 kt) is allowed.

3) *Rotor speed*

The mean value of the rotor speed during the 10 dB-down period is to be within ±1 per cent of the maximum normal operating rotor speed value at the reference take-off condition.

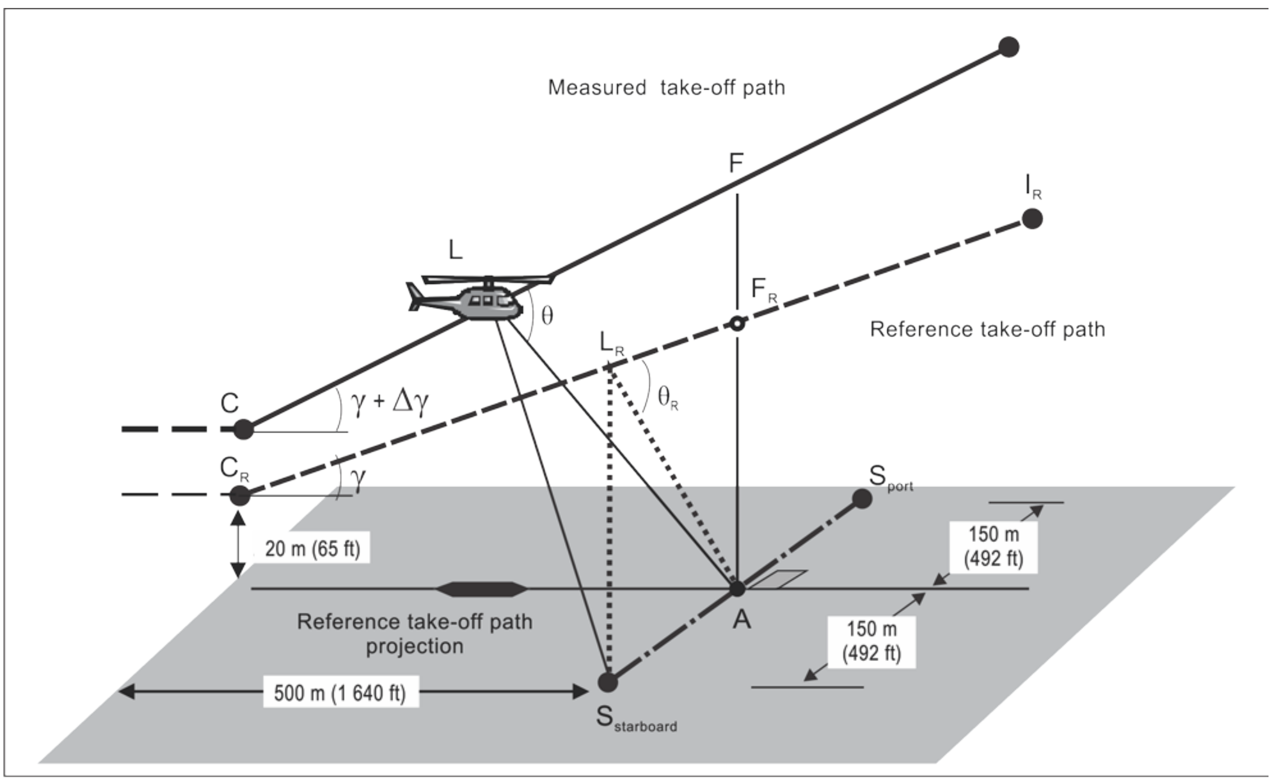


Figure 4-3 Comparison of measured and reference take-off profiles

4) *Flight path deviations*

To minimize lateral flight path deviations, and hence the difference in noise levels due to off-track position at the PNLTM emission point, the aircraft must fly over the reference flight track during the 10 dB-down period within ±10° or ±20 m (±65 ft) from the vertical, whichever is the greater. This is illustrated in Figure 4-4. There is no direct height limitation, but the adjustments that take into account differences between the reference and test sound propagation distances at PNLTM are limited to 2 EPNdB as discussed in GM A2 8.3.1.2 (2).

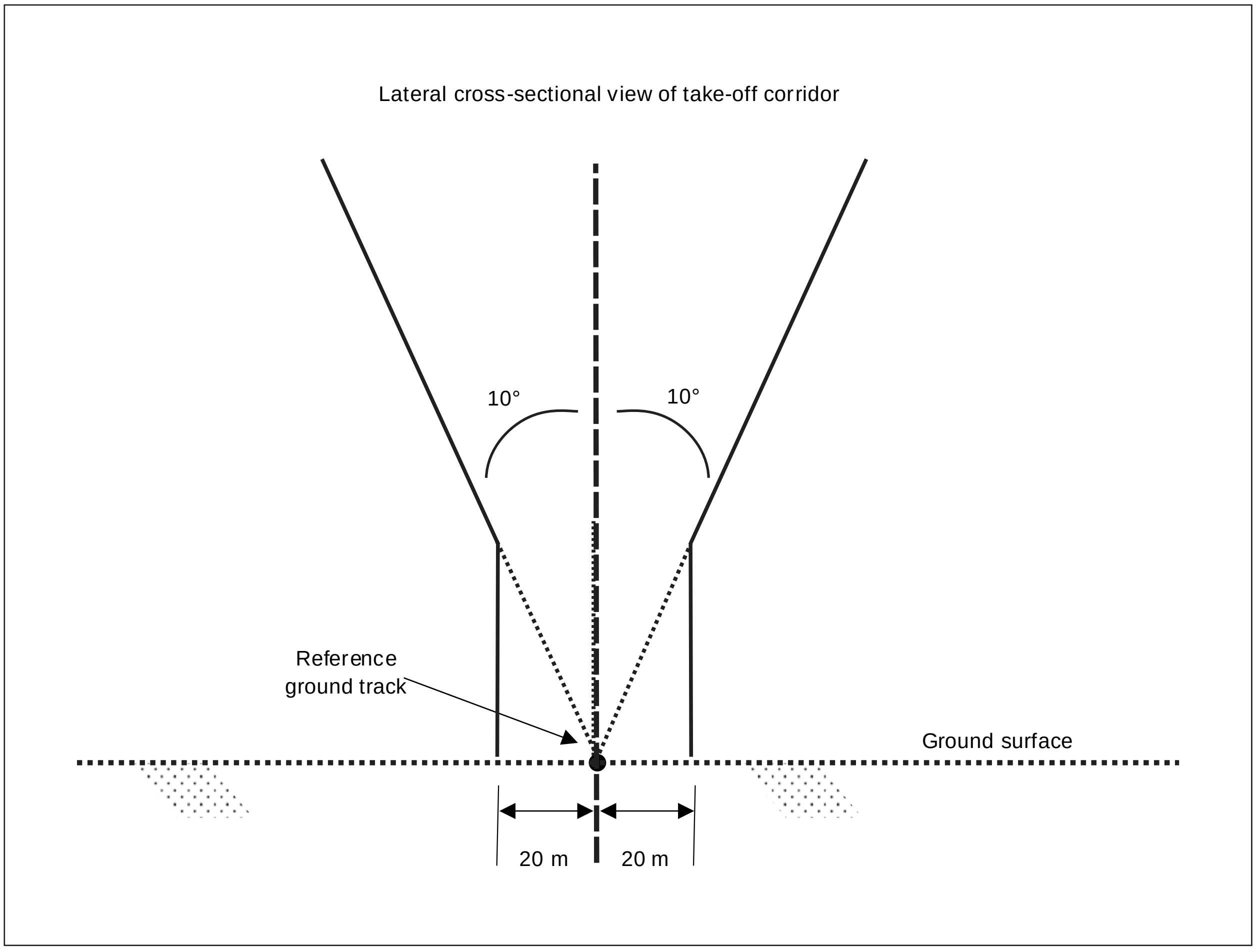


Figure 4-4. Lateral deviation tolerances for take-off

5) *Helicopter and tilt-rotor test mass*

The mass of the aircraft during the noise certification demonstration (see 8.7.11 of Chapter 8 and 13.7.11 of Chapter 13 of the Annex) must lie within the range of 90 per cent to 105 per cent of the maximum take-off mass for the take-off demonstration. No adjustment of the noise data to maximum take-off mass is required. At least one take-off test run must be completed at or above this maximum certificated take-off mass. If the value of the maximum take-off mass selected for noise certification is less than that used for airworthiness certification, then the lower mass may become the operating limitation defined in the appropriate section of the aircraft flight manual.

AMC No. 2 A2 8.1.2.1
[Take-off flight test procedures]

1) *Test take-off profile*

The test take-off profile requires stabilized flight conditions only over the 10 dB-down period in the climb portion of the procedure.

2) *Number of test runs*

At least six test runs are required with simultaneous noise measurements at each of the noise measurement points. It should also be remembered that synchronized noise and flight path data are required. Since it cannot be determined until the analysis is partly completed if each test run meets all the requirements of Chapter 8 or Chapter 13 of the Annex, the applicant will find considerable merit in conducting additional take-off test runs. Experience suggests that 8 to 10 test runs would normally provide an adequate safeguard against some test runs being determined invalid during subsequent analysis. If additional test runs are conducted and more than six valid noise measurements are simultaneously obtained at all three measurement points, then the results of such test runs are also required to be included in the averaging process for calculating EPNL. The results of test runs without simultaneous noise measurements at all three measurement points are not included in the calculation process.

3) *Flight airspeed tolerance*

A ±9 km/h (±5 kt) tolerance about the reference airspeed is specified in 8.7.6 of Chapter 8 and 13.7.6 of Chapter 13 of the Annex. This is not intended to allow tests at different speeds but rather to account for variations during the 10 dB-down period that occur during an individual test run as a result of the pilot attempting to maintain the other take-off requirements and test-to-test variations.

The value of V_Y is published in the take-off performance section of the aircraft flight manual and is typically defined as an IAS. For tilt-rotors the V_Y to be used is that for the nacelle angle used for the take-off condition. The applicant should note the reference airspeed is the true airspeed (TAS). Since most airspeed instruments do not indicate the TAS value, airspeed calibration curves and meteorological conditions should be used to convert between TAS and IAS.

4) *Horizontal adjustment of climb initiation*

Position C in Figure 4-3 may be varied, subject to approval by the certificating authority, to minimize the difference between the test and reference heights vertically above the flight track noise measurement point. This difference can result from the effect of wind on the climb angle during testing. Figure 4-5 illustrates the case of a headwind. Note that even for zero or very low wind, the transition from the horizontal flight to the climb can take a significant time. This will be the case normally on larger and heavier helicopters. The resulting flight path could be well below the reference profile. In this case there would be merit in moving position C further away from the noise measurement point. This is illustrated in Figure 4-6.

5) *Vertical adjustment of climb initiation*

Subject to approval by the certificating authority, the height of the initial level flight may also be varied in order that the height (distance) adjustment associated with the climb phase can be minimized. This is an equivalent procedure, which can be used in the place of adjusting the horizontal location of position C from the flight track noise measuring point to achieve the same result.

The applicant should note that under many test conditions no such adjustments are required to comply with the data adjustment procedures defined in 8.3 of Appendix 2 of the Annex.

Note.— The above procedures for horizontal or vertical adjustment of climb initiation are based on consideration of the height above the flight track or centre noise measuring point, even though the adjustments to the noise measurements are applied for the PNLTM point. However, since the PNLTM point, which is normally within close proximity of the overhead point, cannot be determined until after the noise analysis is conducted, use of height over the noise measuring point to determine the location of position C *(or the initial horizontal height) is acceptable.*

6) *Practice flight*

Irrespective of which method is used to control the height over the flight track noise measurement point, an applicant may find it helpful, if not essential, to conduct a number of practice or pre-noise certification test runs to adjust the height/location of position C. With prior approval of the certificating authority, these practice runs can be excluded from the noise compliance evaluation. These runs should also be documented in the noise certification report as practice flights.

7) *Power setting*

Take-off power at sea level and 25°C has to be applied at position C to initialize the climb. On many aircraft the airworthiness power limit will be set by the take-off gearbox torque limit. When this is not the case, the take-off torque will be that torque determined during the airworthiness certification and will be based on the minimum specification engine(s) power.

In some cases the applicant may find that the take-off gearbox torque limit to which the aircraft is to be airworthiness certificated has not been approved and hence cannot be used during the noise certification test. When testing only at a lower torque is possible, the certificating authority may approve, as an equivalent procedure, the extrapolation of noise data from lower torque settings. Tests conducted at the maximum available, and a minimum of two, lower gearbox torque settings would be required for extrapolation, subject to approval by the certificating authority, to a higher torque value. Experience suggests that extrapolation of no more than 10 per cent is likely to be acceptable. The applicant will also need to document in detail the extrapolation procedure to be used.

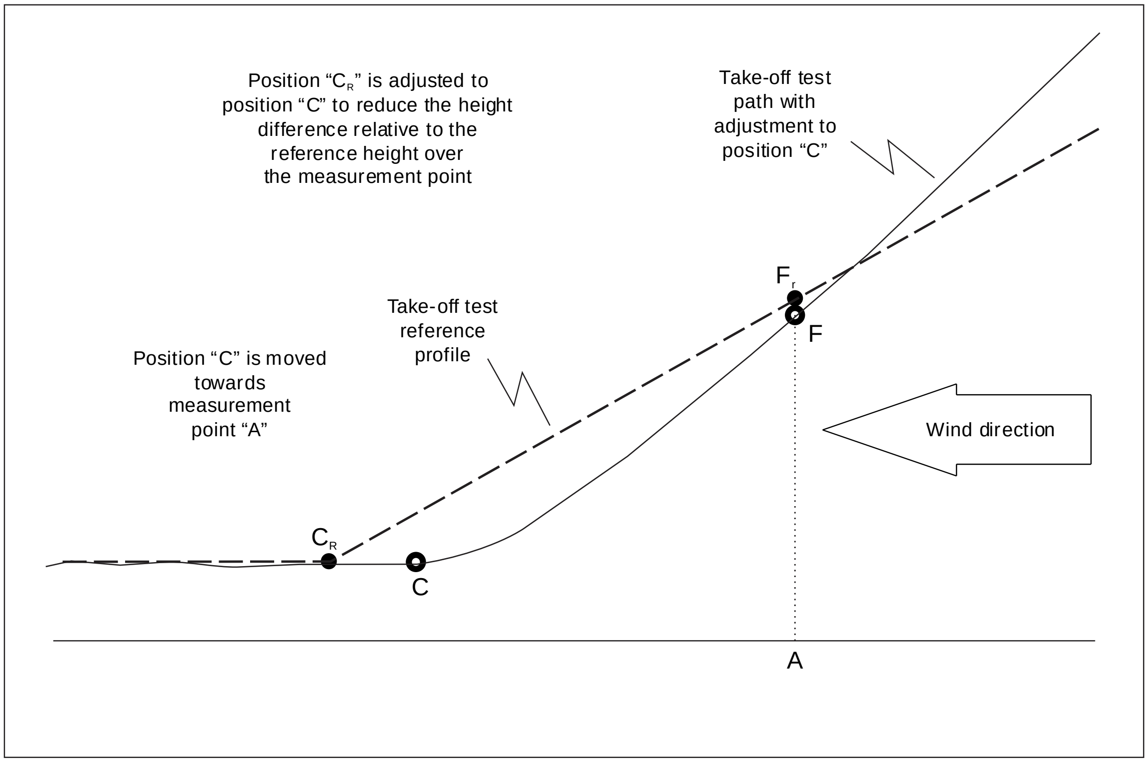


Figure 4-5. Adjustment of take-off profile position "C" for headwind

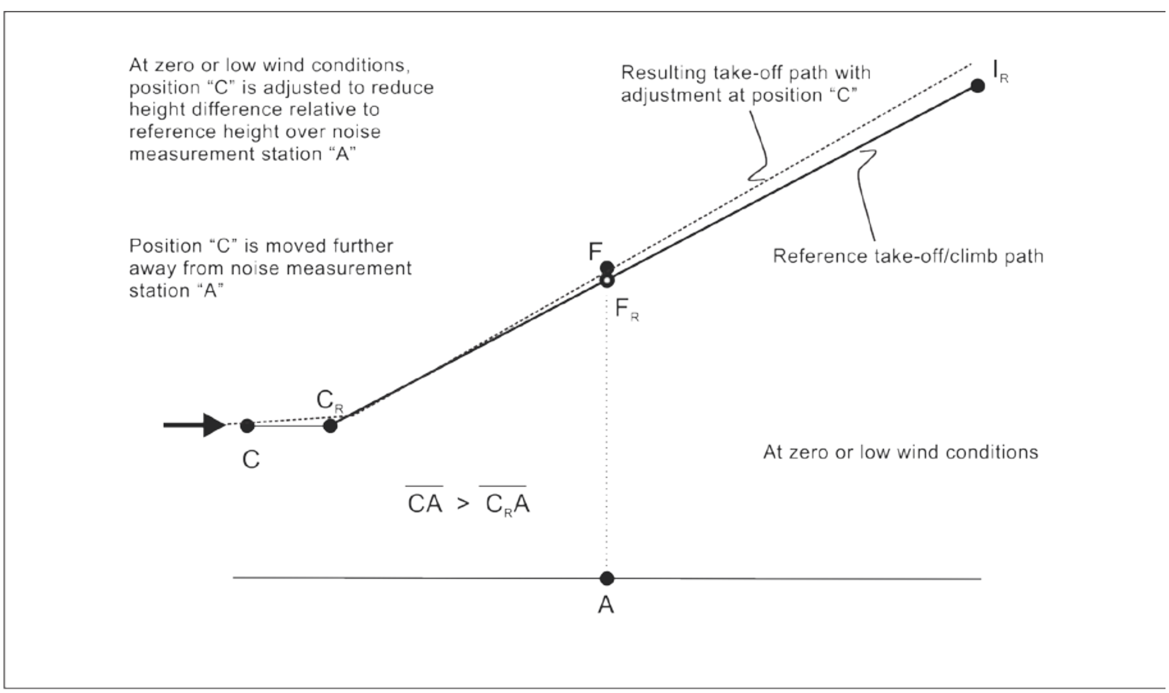


Figure 4-6. Adjustment of take-off profile position "C" for zero or low wind

8) *Rotor speed*

Rotor speed may be manually or automatically varied on some aircraft. On many designs variation in rotor speed can occur due to the limits of the engine/rotor governing system. In order that the noise levels are representative of normal take-off operation, the rotor speed is to be the maximum normal value associated with the reference take-off airspeed. Since on most aircraft small rotor speed changes occur during a stabilized flight, a ±1 per cent rpm variation in the rotor speed is allowed.

Note.— Noise measurements should be made at the maximum rotor speed during normal operations. Testing at the maximum tolerance rpm is not required.

On some aircraft designs more than one rotor speed may be available (see 4.2.3.1.6). If multiple rotor speeds can be used for normal operations, then noise certification has to be conducted at the highest value allowed at the reference conditions. If the highest speed is limited to special operations, or if the aircraft is configured such that the highest rotor speed cannot be used at the reference conditions or test height, then, subject to approval by the certificating authority, testing at a lower rotor speed may be allowed.

On some aircraft designs, rotor speed may be automatically varied within the 10 dB-down period. In such cases, a reference rotor rpm schedule as a function of position along the reference flight path should be defined and tests should be conducted so as to maintain the test rotor rpm within ±1 per cent of the reference rpm schedule. If the variation in rotor speed results in changes to the best rate of climb, a non-linear reference flight profile should be defined and used in the calculation of reference distances for adjustments of the noise data to reference conditions.

For example, for a helicopter that automatically varies rotor speed (N_r) during take-off, a reference rotor speed schedule may be defined as a function of height above ground level along the reference flight path during the 10 dB-down period as illustrated in Figure 4-7. In the typical case where the helicopter is main gearbox torque limited at the noise certification reference conditions, the rotor speed schedule may also result in a non-constant (curved) reference flight path segment during the N_r transition as illustrated in Figure 4-7. The ±1 per cent test requirement for rotor speed would be applied to the reference rotor speed schedule as shown in Figure 4-7.

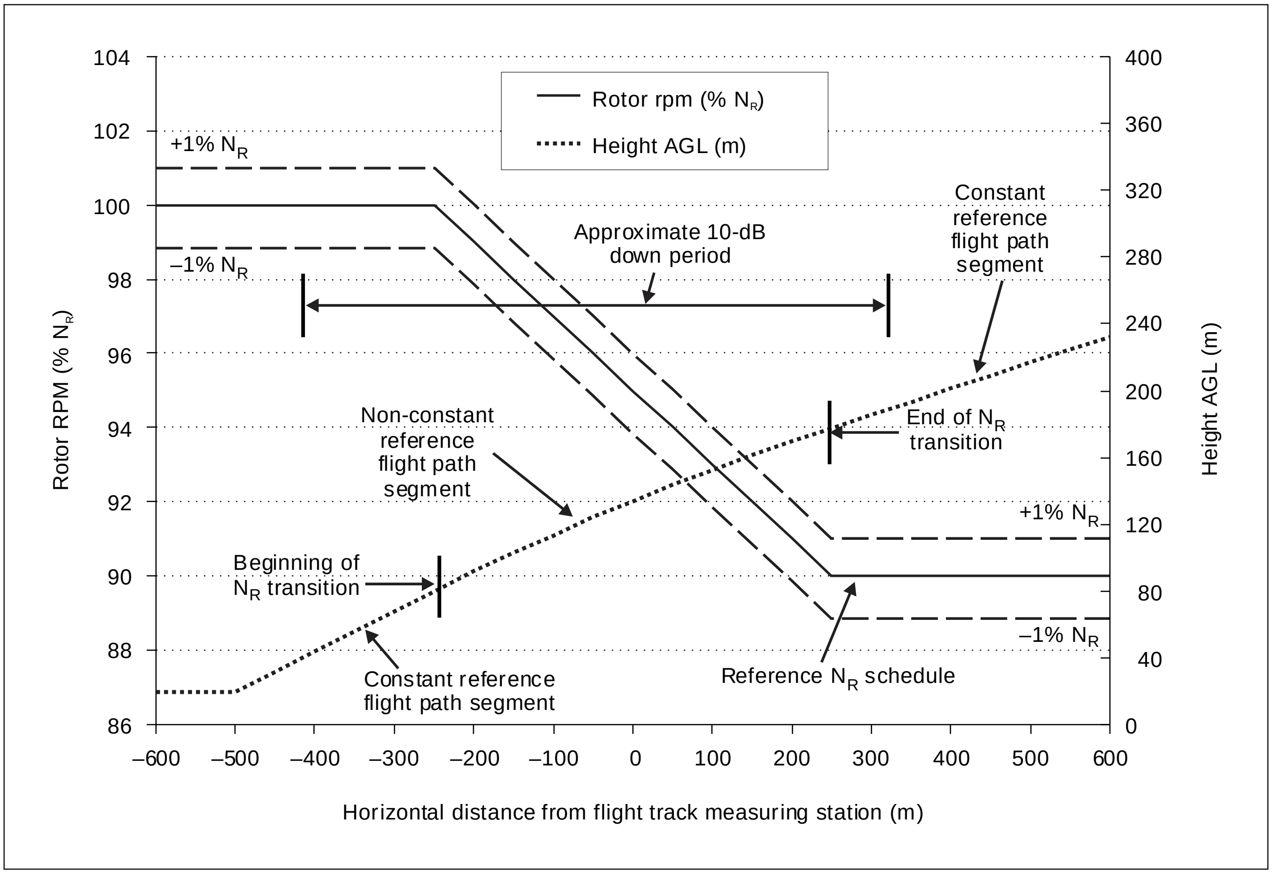


Figure 4-7. Example of a reference take-off flight path and rotor speed schedule (with ±1% Nr limits) for a variable rotor speed helicopter

9) *Flight path guidance*

To meet the requirement of being within ±10° of the vertical, the applicant may need to use flight track markings that are clearly visible and/or on-board flight track guidance instrumentation and a real-time position measuring system or some other approved method of checking that this requirement is satisfied. Pilot visibility of the ground when climbing may be somewhat limited and thus markers well ahead of the noise measuring point may be required. Some of the flight path measurement systems outlined in 3.2, provide flight track data in real time, or in a short period after the test run. In this case the applicant will readily be able to determine if a test run is within the allowable deviation limits. If a simpler system is utilized, such as photographic scaling based on the use of still cameras, the applicant may find it useful, if not essential, to develop a method to enable timely confirmation that the test run is acceptable. The actual height and off-track deviations do not need to be established at the time of the test run. However the applicant needs to ensure that otherwise acceptable test runs are not rejected during analysis for failing to meet the ±10° limit for lateral deviation.

GM No. 1 A2 8.1.2.2
[Overflight configuration]

1) *Reference overflight profile*

Chapters 8 and 13 of the Annex specify the reference procedure as a level overflight at 150 m (492 ft) above the ground at the flight track measurement point as illustrated in Figure 4-8, in which the reference flight profile is indicated as D_r to J_r and the test profile as D to J.

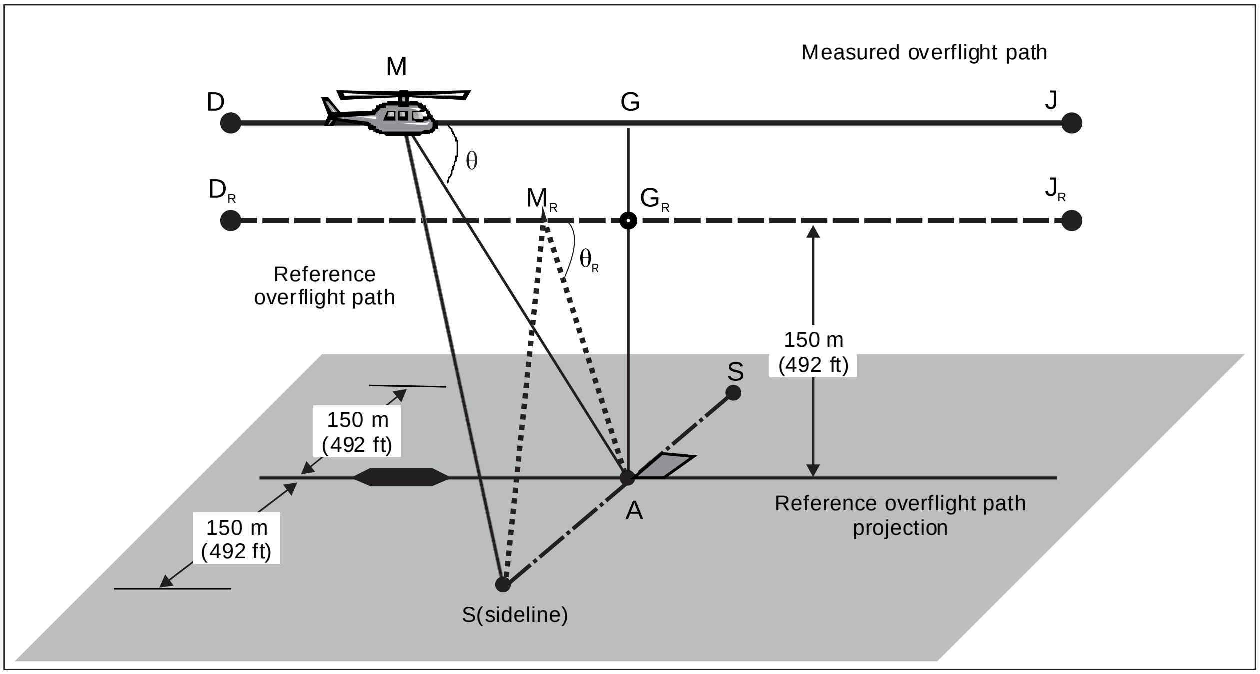


Figure 4-8. Comparison of measured and reference overflight profiles

For helicopters the reference airspeed is 0.9 V_H, 0.9 V_{NE}, 0.45 V_H + 120 km/h (0.45 V_H + 65 kt), or 0.45 V_{NE} + 120 km/h (0.45 V_{NE} + 65 kt), whichever is less, throughout the 10 dB-down period. The rotor speed (rpm) is fixed at the maximum normal operating value. Note that if V_H is greater than V_{NE} then the reference airspeed will be related to V_{NE}.

For tilt-rotors the reference airspeed is 0.9 V_{CON} throughout the 10 dB-down period. The rotor speed (rpm) is fixed at the maximum normal operating value.

Note.— For clarity the location of the test and reference PNLTM *points,* M *and* M_r, *are illustrated at the same position for both the centre line noise measurement point* A *and the lateral noise measurement point location* S. *Normally, however,* M, *and hence* M_r, *will be a different position on the test and reference flight path for each noise measurement point.*

GM No. 2 A2 8.1.2.2
[Overflight test conditions]

1) *Flight path deviations*

To enable the flyover noise characteristics to be obtained, the overflight test has to be a level flight at a fixed height above the flight track noise measurement point. The test runs also have to be within ±10° or ±20 m (±65 ft), whichever is the greater, from the vertical throughout the 10 dB-down period. The ±20 m (±65 ft) is not relevant in the case of overflight since the off-track deviation allowed, at the test height, is controlled by the ±10° requirement.

2) *Test airspeed tolerance*

The flight airspeed is defined in 8.6.3 of Chapter 8 and 13.6.3 of Chapter 13 of the Annex, and a ±9 km/h (±5 kt) tolerance from the reference airspeed during each overflight is allowed within the 10 dB-down period. The power is to be stabilized, and the mean value of the rotor speed during the 10 dB-down period is to be within ±1 per cent of the normal operating rpm value for each overflight.

3) *Source noise adjustment testing*

The applicant should consider the requirement for source noise adjustments since it is unlikely that the tests can be conducted precisely at the reference temperature of 25°C (77°F), reference rotor speed and reference airspeed. This dictates that, if the test advancing blade tip Mach number is different from the reference Mach value, the development of a $PNLTM_R$ versus advancing blade tip Mach number sensitivity curve is necessary. This requires testing at different flight speeds around the reference flight speed. The number of additional test runs will to some extent depend on the character of the variation of $PNLTM_R$ with flight speed, but since this cannot be determined until after the analysis is complete, conservative estimates for the number of additional test runs and the actual airspeeds to be used need to be considered.

Note.— The equivalent Mach number procedure, discussed in AMC A2 8.2.2(10), is an acceptable method of compliance that eliminates the need for a source noise adjustment.

4) *Helicopter and tilt-rotor test mass*

The mass of the aircraft during the noise certification demonstration (see 8.7.11 of Chapter 8 and 13.7.11 of Chapter 13 of the Annex) must lie within the range of 90 per cent to 105 per cent of the maximum take-off mass for the overflight demonstration. At least one overflight test must be completed at or above this maximum certificated mass. If the value of the maximum take-off mass selected for noise certification is less than that used for airworthiness certification, then the lower mass may become the operating limitation defined in the appropriate section of the aircraft flight manual.

AMC A2 8.1.2.2
[Overflight test procedures]

1) V_H

V_H is defined as the airspeed in level flight at the reference conditions and maximum certificated take-off mass and is obtained using the minimum specification engine(s) torque at maximum continuous power. V_H will need to be determined specifically for the noise certification overflight tests, since its determination is not required for the airworthiness certification. V_H, by itself, is never limited by airworthiness considerations. However the maximum continuous power on which it is based may be limited due to airworthiness issues and that, in effect, could limit the value of V_H.

2) *V_{NE}*

V_{NE} is determined as a part of the airworthiness approval and will therefore be readily available.

3) *V_{CON}*

V_{CON} is defined as the maximum authorized speed for VTOL/conversion mode at a specific nacelle angle. The nacelle angle used for the tilt-rotor overflight condition is the authorized fixed operation point that is closest to the lowest nacelle angle certificated for zero airspeed. V_{CON} is determined as a part of the airworthiness approval and will therefore be readily available.

4) *Helicopter reference airspeed*

On some helicopters V_H may be in excess of the level flight V_{NE} imposed and approved by the certificating authority. The intent of noise certification is not to relate test airspeeds to reference airspeeds that may be beyond the airworthiness V_{NE} limit of the helicopter. Under 8.6.3 of Chapter 8 of the Annex, V_{NE} would therefore apply in place of V_H. Also on some helicopters with high airspeed capabilities, the typical cruise airspeed will be less than 0.9 V_H (or 0.9 V_{NE}) and thus if 0.9 V_H (or 0.9 V_{NE}) were used as the reference, it would no longer be representative of a cruise flight. In this case a lower airspeed of 0.45 V_H + 120 km/h (0.45 V_H + 65 kt) or 0.45 V_{NE} + 120 km/h (0.45 V_{NE} + 65 kt) is used. This applies when 0.9 V_H (or 0.9 V_{NE}) is 240.8 km/h (130 kt) or higher (i.e. when V_H (or V_{NE}) is 267.6 km/h (144.4 kt) or higher). Thus the reference airspeed will be the least of the following four airspeeds:

a) 0.9 V_H;

b) 0.45 V_H + 120 km/h (0.45 V_H + 65 kt);

c) 0.9 V_{NE}; or

d) 0.45 V_{NE} + 120 km/h (0.45 V_{NE} + 65 kt).

5) *Flight path/height determination*

The flight path is required to be “straight and level”. Since there is no requirement for the terrain over which the helicopter is flying to be perfectly level, the height of the aircraft above the ground may vary slightly over the distance corresponding to the 10 dB-down period. If a ground-based system such as a differential GPS base station or a three-camera system is used, then the flight path/height determination will need to account for the actual ground elevations at which the system components are placed.

6) *Flight track deviations*

The allowable off-track deviation from the vertical above the reference track is limited by ±10° or ±20 m (±65 ft), whichever is the greater. The height above the flight track noise measurement point must be within ±9 m (±30 ft) of the reference height of 150 m (492 ft). The allowed off-track deviation is ±24.9 m (±81.5 ft) at the lower height limit of 141 m (462 ft) and is ±28 m (±92 ft) at the higher height limit of 159 m (522 ft). Thus the helicopter must pass through a “test window” located above the reference flight track, as illustrated in Figure 4-9, throughout the 10 dB-down period.

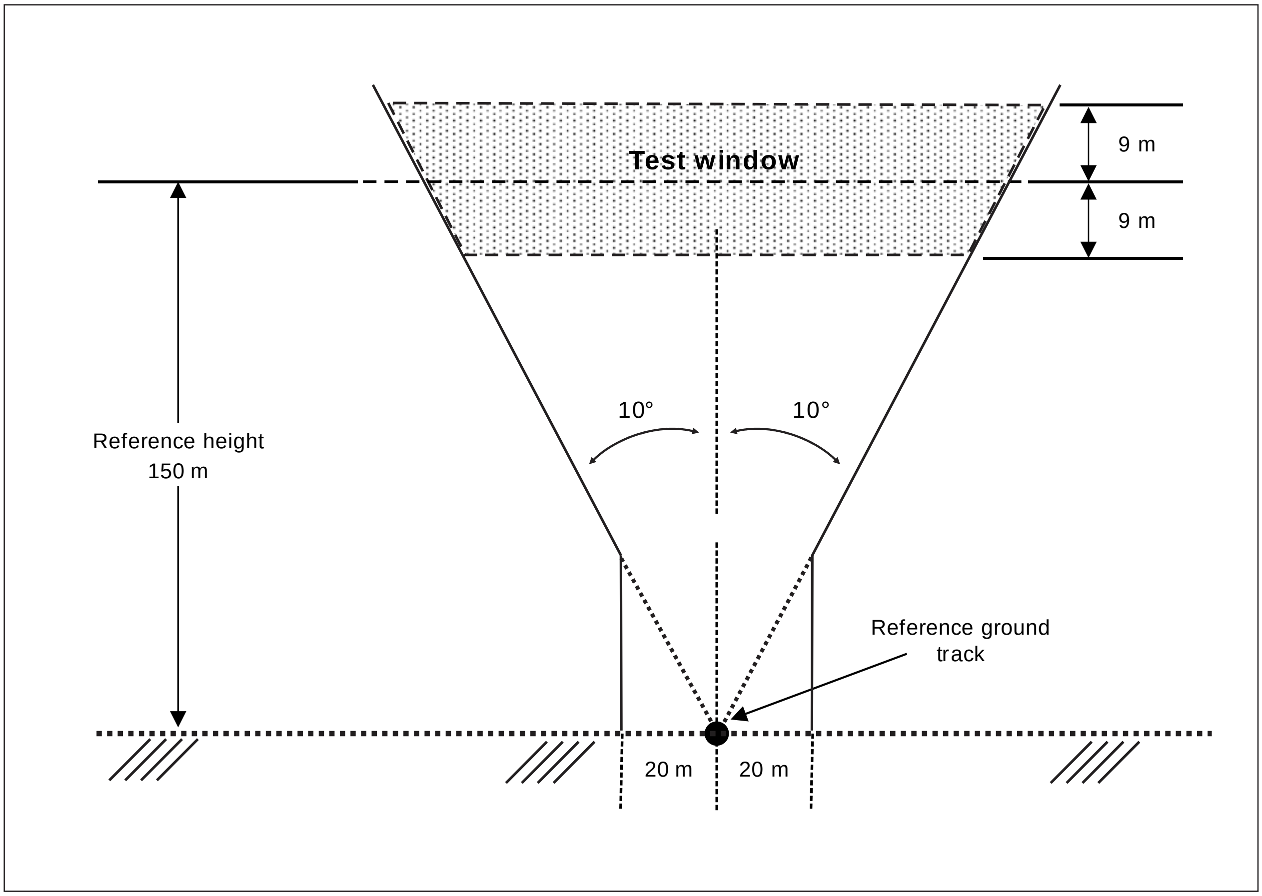


Figure 4-9. Flight boundaries for overflight test condition

7) *Number of test runs*

At least six overflight test runs are required, with equal numbers with headwind and tailwind. Since the data will be adjusted, there are no requirements for these to be flown in pairs immediately one after the other. Conducting the test runs in pairs, however, would alleviate the need to take the wind direction into account. The applicant will therefore typically find it expedient to conduct tests in such a manner and include additional pairs of test runs in case any of the test runs are proved invalid on subsequent analysis. In addition to the simultaneous noise measurement at the three measurement points, the applicant should note that synchronized noise and flight path measurements are required throughout the 10 dB-down period. If additional test runs are conducted and more than six valid noise measurements are simultaneously obtained at all three measurement points, then the results of such test runs are also required to be included in the averaging process for calculating EPNL. The results of test runs without simultaneous noise measurements at all three measurement points are not included in the calculation process.

Note.— If the absolute wind speed component in the direction of flight, as measured at a height of 10 m (33 ft) above ground, is less than 2.6 m/s (5 kt), then the effect of wind direction can be considered to be negligible. In this case the measured overflight can be considered to be either a headwind or tailwind test run.

8) *Test height*

Since most test sites will not be completely flat, the height (distance) between the aircraft and ground track will vary during the overflight. The flight path and the relative position between the aircraft and the reference profile can be determined using a number of different systems (see 3.2).

9) *Test airspeed*

The overflight test airspeed will be either the reference airspeed if a source noise adjustment is applied, or the adjusted reference airspeed if the equivalent Mach number method is used. The applicant should also note that the airspeed defined in the Annex is the true airspeed (TAS). Since most airspeed instruments do not indicate the TAS value, airspeed calibration curves and test-day meteorological conditions should be used to determine the IAS for use by the pilot.

10) *Source noise adjustment*

Source noise adjustments have to be developed for noise data measured at the centre, left sideline and right sideline microphones. Test runs are conducted in two directions. “Left sideline” and “right sideline” are defined relative to the direction of flight for each test run. It follows that if a microphone is “left sideline” for a test run in one direction then it is “right sideline” for a test run in the other direction. The applicant should take care to ensure the measured noise is correctly designated.

Two methods have been adopted by various applicants to establish the source noise adjustment. The first involves testing, relative to the reference flight speed, at a number of fixed airspeeds such as V_R – 19 km/h (10 kt), V_R – 37 km/h (20 kt) and V_R + 19 km/h (10 kt). To retain the same accuracy as associated with the reference condition, six test runs (three in each direction) at each of the additional flight airspeeds are typically needed. A sensitivity curve is then developed from this data as indicated in Figure 4-10. Other applicants have tested over a range of airspeeds from, for example, V_R – 37 km/h (20 kt) to V_R + 19 km/h (10 kt) and developed a sensitivity curve in this manner. In this case at least six valid test runs are of course still required at the reference airspeed. A statistically acceptable curve using this method is illustrated in Figure 4-11. The number of test runs required for either method for developing source noise sensitivity curves is subject to approval by the certificating authority.

11) *Equivalent Mach number test procedure*

To avoid testing at a large number of airspeeds over a wide airspeed range to develop a $PNLTM_R$ versus a Mach number sensitivity curve, the applicant may, subject to approval by the certificating authority, use the equivalent procedure presented in 4.2.3.2.2. With this procedure a single series of test runs is conducted at an adjusted reference airspeed. The minimum number of acceptable test runs is six (three in each direction), and the previous comments on the need for the applicant to consider making additional test runs to cover the case where some test runs may subsequently be found to be invalid is equally applicable. When this procedure is used the airspeed tolerance is reduced from ±9 km/h (±5 kt) to ±5.5 km/h (±3 kt). In addition all the other limits applicable to testing at the reference airspeed also apply.

This equivalent procedure requires measurement of the on-board outside air temperature just prior to each test run. Under stable ambient temperature conditions this is relatively straightforward and calculations can be made on the ground prior to each test run. When changes in temperature are occurring during the test period, it may be necessary to take the on-board temperature in flight just prior to reaching the initial 10 dB-down point. These can be used to make the necessary calculations to adjust the flight airspeed appropriately and ensure that the applicable adjusted airspeed and reference advancing blade tip Mach number are used for the test run.

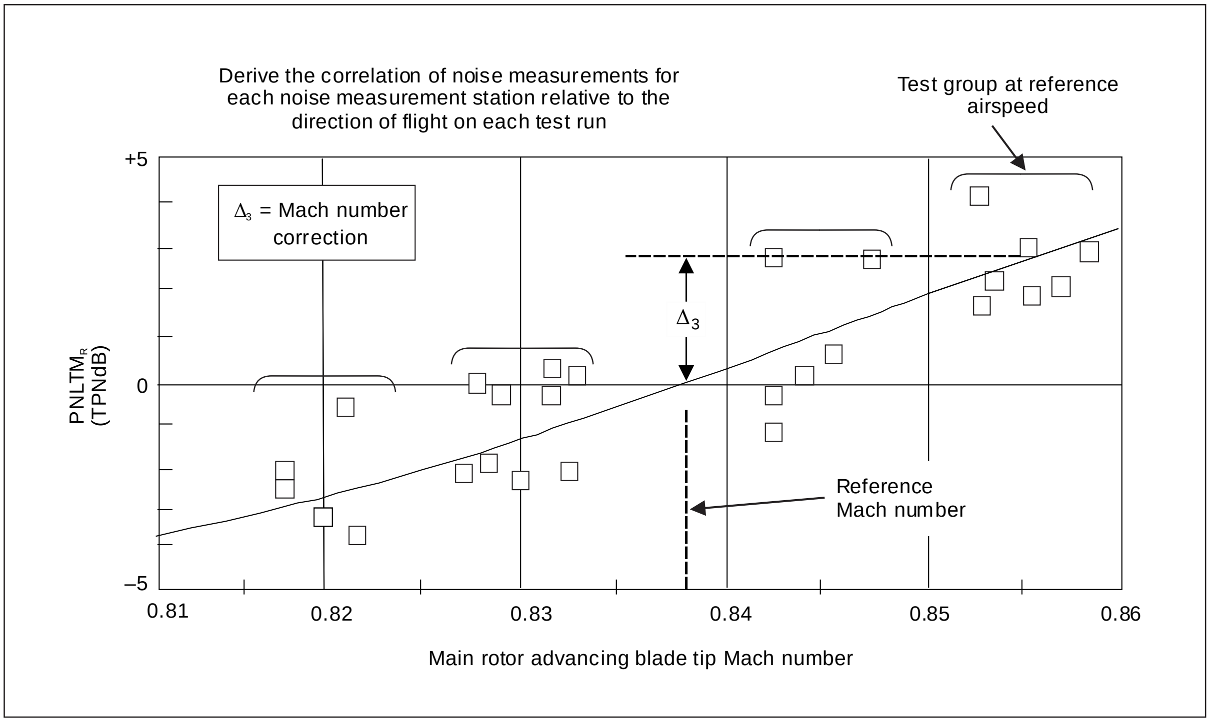


Figure 4-10. Example of source noise correlation using pooled (clustered) test data

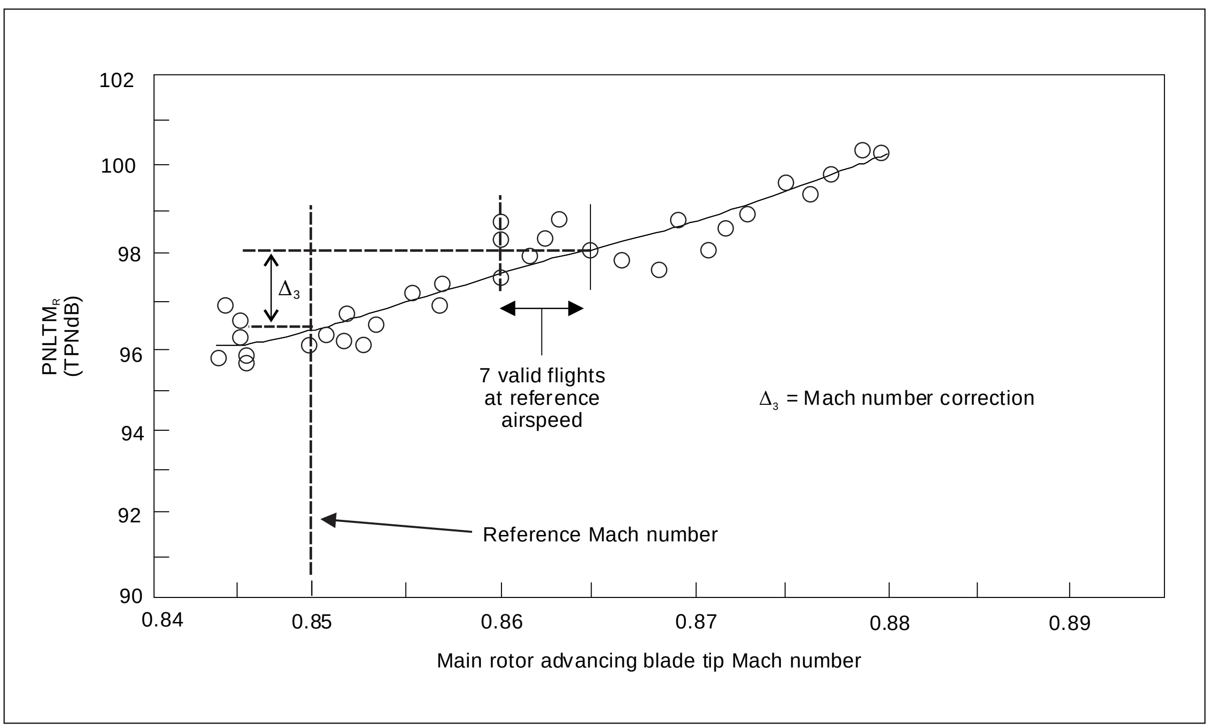


Figure 4-11. Example of source noise correlation using distributed test data

When this equivalent procedure is used the test runs are conducted at the reference blade tip Mach number, and hence no additional source noise adjustments are required. The applicant should also note the airspeed defined in the Annex is the true airspeed (TAS), and since most airspeed instruments do not indicate the TAS value, airspeed calibration curves and test-day meteorological conditions should be used to determine the IAS for use by the pilot.

12) *Equivalent Mach number test speed*

Each overflight noise test must be conducted such that the adjusted reference true airspeed, V_{AR}, is the reference airspeed (V_R specified in 8.6.3.1 of Chapter 8 and 13.6.3.1 of Chapter 13 of the Annex), adjusted as necessary to produce the same main rotor advancing blade tip Mach number as associated with reference conditions.

Note 1.— For helicopters the reference advancing blade tip Mach number, M_{ATR}, is defined as the ratio of the arithmetic sum of the reference main rotor blade tip rotational speed, V_{tipR}, and the helicopter reference speed, V_R, divided by the speed of sound, c_R, at 25°C (346.1 m/s) such that:

$$M_{ATR} = \frac{V_{tipR} + V_R}{c_R}$$

and the adjusted reference airspeed, V_{AR}, is calculated from:

$$V_{AR} = c\left(\frac{V_{tipR} + V_R}{c_R}\right) - V_{tipR}$$

where c is the speed of sound calculated from the on-board measurement of outside air temperature.

Note 2. — For tilt-rotors, the reference advancing blade tip Mach number, M_r, is defined as the ratio of the vector sum of the reference rotor blade tip rotational speed, V_{tipR}, and the tilt-rotor reference speed, V_R, divided by the speed of sound, c_R, at 25°C (346.1 m/s) such that:

$$M_R = \frac{\left[V_{tipR}{}^2 + V_R{}^2 - 2 \times V_{tipR} \times V_R \times \cos\left(I_N + 90^\circ\right)\right]^{1/2}}{c_R}$$

where I_N is the nacelle incidence angle in degrees for the overflight condition. The adjusted reference airspeed, V_{AR}, is calculated from:

$$V_{AR} = V_{tipR} \times \cos\left(I_N + 90^\circ\right) + \left(V_{tipR}^2 \times \cos\left(I_N + 90^\circ\right)^2 + \left(\frac{c}{c_R}\right)^2 \left(V_{tipR}^2 + V_R^2 - 2 \times V_{tipR} \times V_R \times \cos\left(I_N + 90^\circ\right)\right) - V_{tipR}^2 \right)^{1/2}$$

where c is the speed of sound calculated from the on-board measurement of outside air temperature.

13) *Rotor speed/flight path guidance*

The comments on rotor speed and flight path guidance discussed in AMC No. 2 A2 8.1.2.1 are equally applicable for overflight noise testing.

GM No. 1 A2 8.1.2.3
[Approach configuration]

1) *Reference approach profile*

The reference approach profile is illustrated in Figure 4-12 together with an idealized measured test profile. The Annex requires flight tests to be conducted under stable flight conditions within a 6° ± 0.5° approach angle with the noise data adjusted to a 6° reference profile. The reference airspeed is V_Y, as used for the take-off test, or the lowest airworthiness-approved speed for approach, whichever is the greater.

Note.— For clarity the location of the test and reference PNLTM *points,* N *and* N_r*, are illustrated at the same position for both the centre line noise measurement point* A *and the starboard lateral noise measurement point* S. *Normally however* N, *and hence* N_r, *will be a different position on the test and reference flight paths for each noise measurement point.*

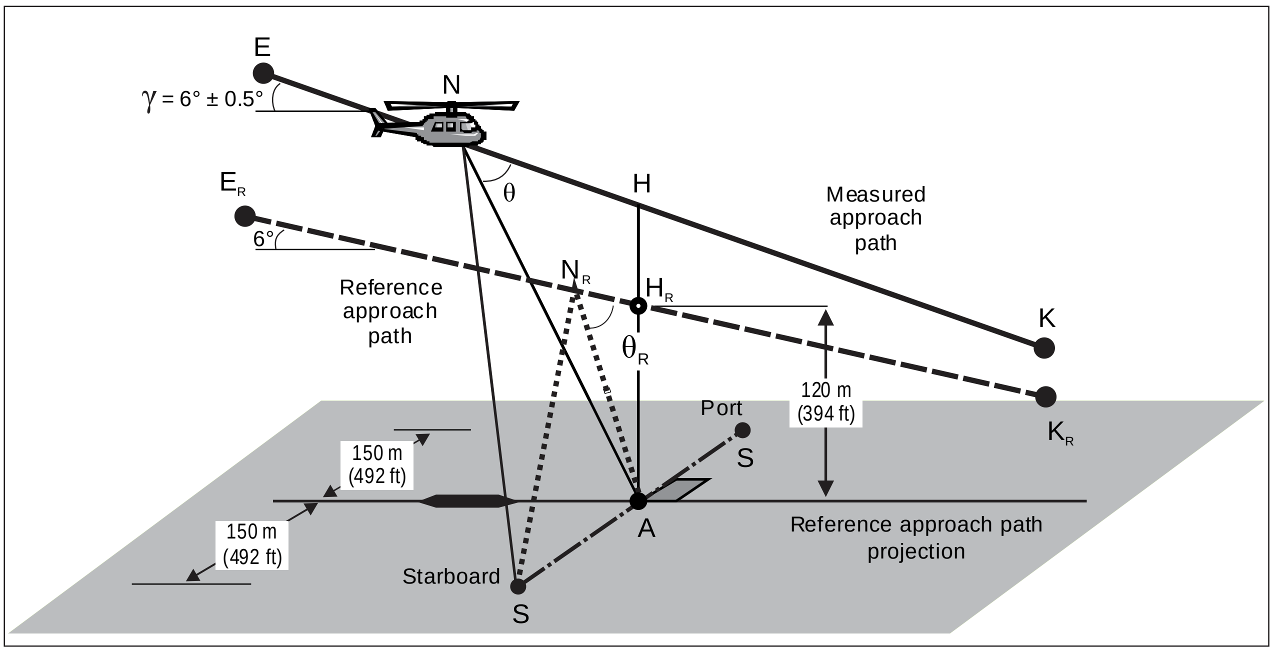


Figure 4-12. Comparison of measured and reference approach profiles

2) *Reference approach path*

The touchdown position is located 1 140 m (3 740 ft) from the intersection of the 6° reference approach path with the ground plane through position A. The flight path reference point, H_r, is located 120 m (394 ft) above position A on the ground.

3) *Helicopter and tilt-rotor test mass*

The mass of the aircraft during the noise certification demonstration (see 8.7.11 of Chapter 8 and 13.7.11 of Chapter 13 of the Annex) must lie within the range of 90 per cent to 105 per cent of the maximum landing mass for the approach demonstration. At least one approach test must be completed at or above this maximum certificated mass. For most aircraft the maximum landing mass will be the same as the maximum take-off mass and, as a result, the same maximum mass will apply to all three test conditions. If the value of the maximum landing mass selected for noise certification is less than that used for airworthiness certification, then the lower mass may become the operating limitation defined in the appropriate section of the aircraft flight manual.

GM No. 2 A2 8.1.2.3
[Approach test conditions]

1) *Test airspeed*

Since there is no single common or well-defined approach airspeed applicable to helicopters or tilt-rotors, the tests are conducted at the certificated best rate of climb airspeed, V_Y, which approximates to a typical approach speed, or the lowest airworthiness approved speed for approach, whichever is the greater. For tilt-rotors the V_Y to be used is that for the nacelle angle used for the approach condition.

2) *Flight path deviations*

Test runs are to be conducted with a 6° ± 0.5° approach angle using stabilized flight airspeed within ±9 km/h (±5 kt) of the reference V_Y airspeed, rotor speed within ±1 per cent of the normal maximum operating rotor speed, and power. To limit the magnitude of the off-track distance, the flight path is to be maintained to within ±10° or ±20 m (±65 ft) of the vertical, whichever is the greater, throughout the 10 dB-down period (see Figure 4-13).

3) *Maximum noise level measurement*

The intent of the Standard is to obtain noise measurements of the maximum noise levels that are likely to occur in practice during an approach flight condition. Since it is known that the maximum main rotor noise, known as blade-vortex interaction (BVI) or blade slap, occurs at around 6º descent angle at a constant speed of V_Y, this has been chosen as the reference condition. Only in the case where the lowest airworthiness-approved speed for approaches is greater than V_Y can any approach angle exception be allowed. This would require approval by the certificating authority and, irrespective of approved angle, the height above the ground at the flight-track measurement point would have to be 120 ± 10 m (394 ± 33 ft).

Experience suggests however that normally there is little difficulty in conducting the approach test with a descent angle of 6° at an airspeed of V_Y within the allowable limits of ±0.5° and ±9 km/h (±5 kt), respectively.

4) *Blade vortex interaction*

Since a 6° descent angle at a speed of V_Y is the approach condition likely to give the highest level of main rotor BVI, the applicant should note that although on some aircraft this will result in a steady noise signature, on other aircraft the BVI noise character can vary even under nominally steady flight conditions. This may be subjectively noticeable but is not a technical problem since the average of six test runs will normally give results well within the maximum acceptable 90 per cent confidence interval of ±1.5 EPNdB.

5) *Practice flights*

Flying a constant 6º approach angle at a constant airspeed may be a somewhat demanding requirement for some aircraft, particularly since, in practice, a decelerating approach at a varying descent angle is the common method utilized in aircraft operations. The applicant/pilot may find merit, therefore, in the test procedure being practised prior to any noise certification testing.

AMC A2 8.1.2.3
[Approach test procedures]

1) *Reference approach procedure*

The 6° reference procedure is defined as being under stable flight conditions in terms of torque, rotor speed, airspeed and rate of descent, and in the case of tilt-rotors nacelle angle and flap setting, throughout the 10 dB-down period. The reference airspeed is the best rate of climb true airspeed (TAS), V_Y, approved by the certificating authority.

2) *Number of test runs*

At least six test runs are required with simultaneous noise measurements at each of the noise measurement points. The applicant should, as in the case of take-off and overflight, consider additional test runs to ensure that a sufficient number of valid data points are available. Synchronized noise and flight path measurements are required throughout the 10 dB-down period. If additional test runs are conducted and more than six valid noise measurements are simultaneously obtained at all three measurement points, then the results of such test runs are also required to be included in the averaging process for calculating EPNL. The results of test runs without simultaneous noise measurements at all three measurement points are not included in the calculation process.

3) *Flight path guidance*

The aircraft has to fly within the 6° ± 0.5° approach angle range and within ±10° or ±20 m (±65 ft), whichever is greater, of the vertical above the reference flight track throughout the 10 dB-down period. Thus the aircraft has to fly within a "rectangular funnel" as illustrated in Figure 4-13. To ensure flight within these limits, positive guidance to the pilot will most likely be required. This guidance can take many different forms, varying from on-board instrumentation providing, for example, a box in which the pilot flies the aircraft, cross hairs where the pilot flies the aircraft at the centre, or an external light guidance system such as a visual approach slope indicator (VASI) or pulsating light approach slope indicator (PLASI) located at or near the imaginary touchdown point where the 6° angle reaches the ground. The system chosen by the applicant should be approved by the certificating authority prior to testing.

4) *Flight path intercept*

Section 8.1.2.3 of Appendix 2 of the Annex specifies that each approach test run be continued to a normal touchdown. The noise data are taken during stabilized flight conditions within the 10 dB-down period and thus may not be impacted by the flare or the final touchdown. Also, for flight safety reasons, it may not be desirable to continue the test run on a 6° profile to the ground. As a result an equivalent procedure may be used, subject to approval by the certificating authority, where the aircraft can break off from the descent after the second 10 dB-down point is reached. This can be completed without the need to actually land the aircraft, offering considerable savings in flight time, providing the other requirements are met.

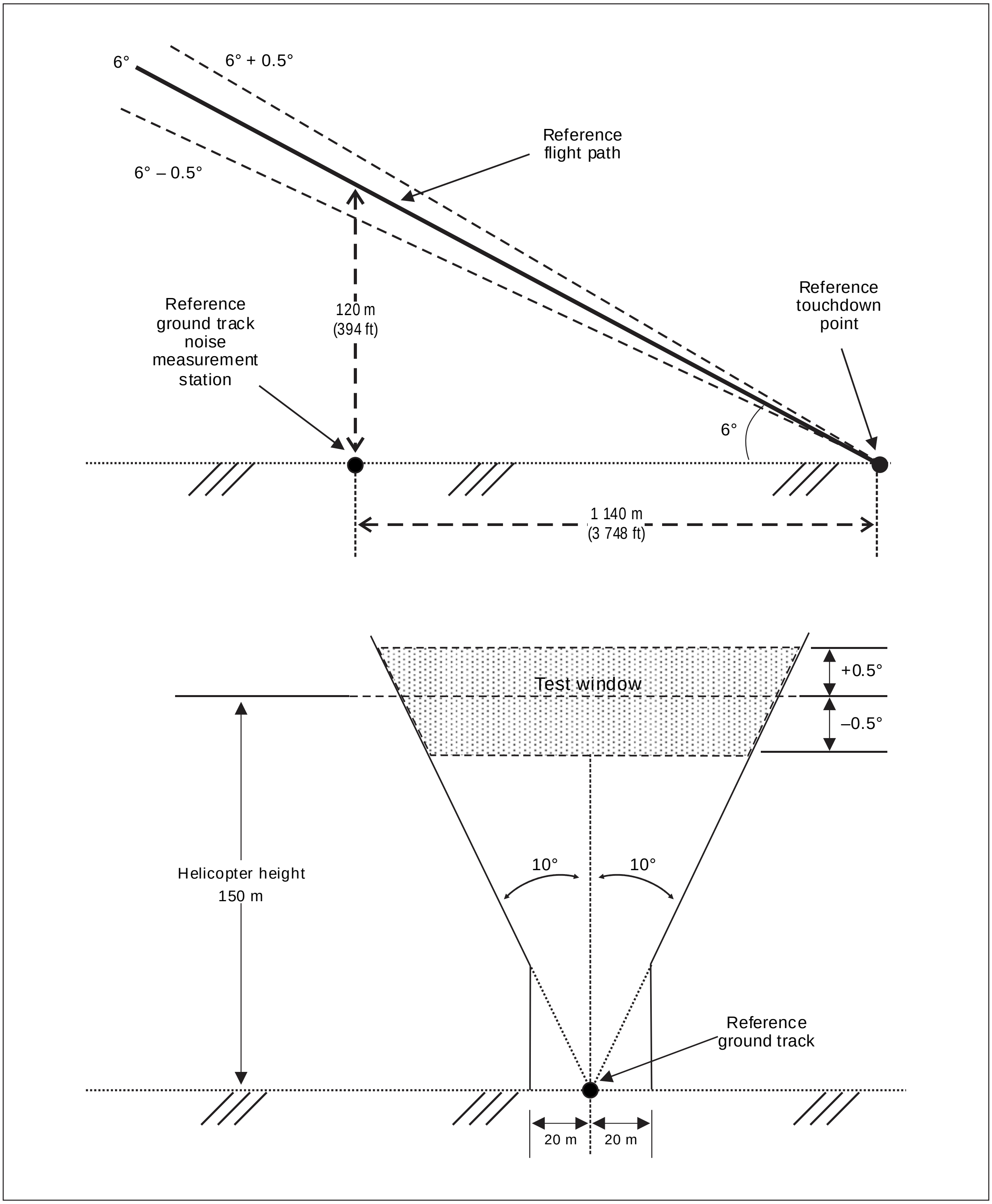


Figure 4-13. Flight boundaries for approach test condition

5) *Wind direction*

Although the Annex does not specifically require that the test runs be conducted into the wind, this is advisable since it will provide a safer and more stable flight environment.

6) *Rotor speed guidance*

The comments on rotor speed guidance discussed in AMC No. 2 A2 8.1.2.1 are equally applicable for approach noise testing.

7) *Other test requirements*

The comments on the height, flight airspeed variation and rotor speed measurements discussed in AMC A2 8.2.2 are equally applicable for approach.

GM A2 8.3.2
[Adjustments of PNL and PNLT]

1) *Units*

For calculations in SI units, the distances are measured in metres and $\alpha(i)$ and $\alpha_R(i)$, used in determining Δ_1, are expressed in dB/100 m. In this case a constant factor of 0.01 is used for the first and second terms of the Δ_1 adjustment. If the U.S. Customary (English) system of units is used the distances are measured in feet and $\alpha(i)$ and $\alpha_R(i)$ are expressed in dB/1 000 ft. In this case a constant factor of 0.001 is used for the first and second adjustment terms.

2) *Zero adjustment test window*

If the test conditions fall within the "zero attenuation adjustment window" shown in Figure 4-29 of 4.2.3.2.1, the sound attenuation adjustment for the effects of atmospheric absorption of the test data may be taken as zero subject to prior approval by the certificating authority (see 4.2.3.2.1 for details).

AMC A2 8.3.4
[Duration adjustment to EPNL]

1) *Adjustment for flight path*

The distances associated with the PNLTM position used to calculate the adjustments under 8.3 of Appendix 2 of the Annex are used in the calculation of the first term of the Δ2 duration adjustment to EPNL.

Note.— If the test conditions fall within the window shown in Figure 4-29 of 4.2.3.2.1, the ratios of the reference and test slant distances for the propagation path adjustments in the first term of the adjustments to the duration correction may be replaced by the ratios of the reference and test distances to the helicopter when it is overhead the flight track noise measurement point (see 4.2.3.2.1 for details).

2) *Adjustment for ground speed differences*

The ground speed must not be confused with the actual airspeed used during the tests and will be a function of both the flight test airspeed and wind speed. The reference ground speed, V_{GR} (based on the assumption of a zero wind condition) is, for take-off and approach, the horizontal component of the reference airspeed,

V_Y (in true airspeed) defined in 8.6.2 and 8.6.4 of Chapter 8 and 13.6.2 and 13.6.4 of Chapter 13 of the Annex and, for overflight, the reference airspeed defined in 8.6.3 of Chapter 8 and 13.6.3 of Chapter 13 of the Annex. For take-off the reference ground speed V_{GR} is the reference airspeed V_Y times the cosine of the reference climb angleγ_R

3) *Microphone height*

To make the necessary adjustments, the microphone height above the ground, 1.2 m (4 ft), is to be taken into account when calculating the sound propagation path from the position at which the PNLTM occurs, to the microphone.

Note.— For each noise measurement point during each test run, the PNLTM will normally occur at a different position on both the test and reference flight paths.

4.1.9 Adjustment of aeroplane flight test results

GM A2 8.2
[Adjustments to reference conditions]

1) *Adjustments to reference conditions*

Most noise certification tests are conducted during conditions other than reference conditions. During these tests the aeroplane may be at a different height over the microphone, or deviate laterally from the intended flight path. The engine thrust (power), atmospheric conditions, aeroplane height and/or gross mass might also differ from reference conditions. Therefore, measured noise data should be adjusted to reference conditions to determine whether compliance with the noise certification limits of Chapter 3 or 4 of the Annex may be achieved. Adjustment procedures and analysis methods should be reviewed and approved by the certificating authority. The certificating authority should ensure that data adjustment and analysis methods that are proposed by applicants satisfy the requirements of the Annex and approved procedures. Any changes, including software revisions, firmware upgrades or instrumentation changes, are subject to review by the certificating authority before they can be used for noise certification evaluations. Programme validation should be planned and the required information submitted to the certificating authority early in the certification cycle, since the time required for evaluation and approval may vary depending on the issues encountered.

2) *Non-positive SPLs*

Whenever non-positive one-third octave band aircraft noise levels are obtained, whether as part of the original one-third octave band analysis or as a result of adjustments for background noise, or other approved procedures, their values should be included in all relevant calculations. The practice of “band-dropping”, where masked levels are methodically set equal to zero, is not considered to be an acceptable substitute for reconstruction of masked levels as per the background noise adjustment guidance provided in 3.6.3. For any aircraft noise spectrum subject to adjustment to reference conditions, all one-third octave bands, including those containing masked levels or reconstructed levels, including values less than or equal to zero dB, should be adjusted for differences between test and reference conditions.

3) *High altitude test sites*

For test sites at or above 366 m (1 200 ft), data shall be adjusted to account for jet noise suppression due to the difference in the engine jet velocity and jet velocity shear effects resulting from the change in air density. This adjustment is described in 4.3.2.3.

GM A2 8.2.1
[Origin of reference data]

1) *Manufacturer's data*

Adjustment of noise values from test to reference conditions should be based on approved manufacturer's data. Manufacturer's data should include:

a) reference flight profiles during take-off with maximum gross mass;

b) flyover, lateral and approach engine thrust (power) or thrust settings at reference conditions;

c) engine cutback thrust (power) reduction requirements at reference flyover conditions;

d) data defining negative runway gradients (not applicable when an applicant uses flight path intercept techniques); and

e) reference airspeeds during flyover, lateral and approach tests at maximum gross mass.

GM A2 8.1.1.2
[Take-off configurations]

1) *Take-off tests*

The reference take-off configuration selected by the applicant should be within the approved airworthiness certification envelope. Special flight crew procedures or aircraft operating procedures are not permitted.

2) *Take-offs with thrust (power) reduction*

Figures 4-14 and 4-15 illustrate an example of the effect of thrust (power) reduction on the PNLT time history and the associated flight path. After thrust (power) reduction a slight decrease in the climb gradient may occur due to the thrust (power) lapse that results from increased height during the 10 dB-down period.

3) *Full thrust (power) take-offs*

Full thrust (power) take-offs are also permitted as the reference flyover noise certification procedure and are a requirement for the lateral noise certification procedure. Maximum approved take-off thrust (power) is to be used from the start-of-roll (see point A in Figure 4-16). Lift-off from the runway is at point B, after which the landing gear is retracted and flap positions adjusted. At point C, the stabilized climb angle and airspeed are achieved while maintaining full take-off thrust (power). The aeroplane continues to climb until sufficiently past point F to ensure that the 10 dB-down time noise value is measured at point K. Between points C and F, the thrust (power), flight path and aircraft configurations are to be kept constant.

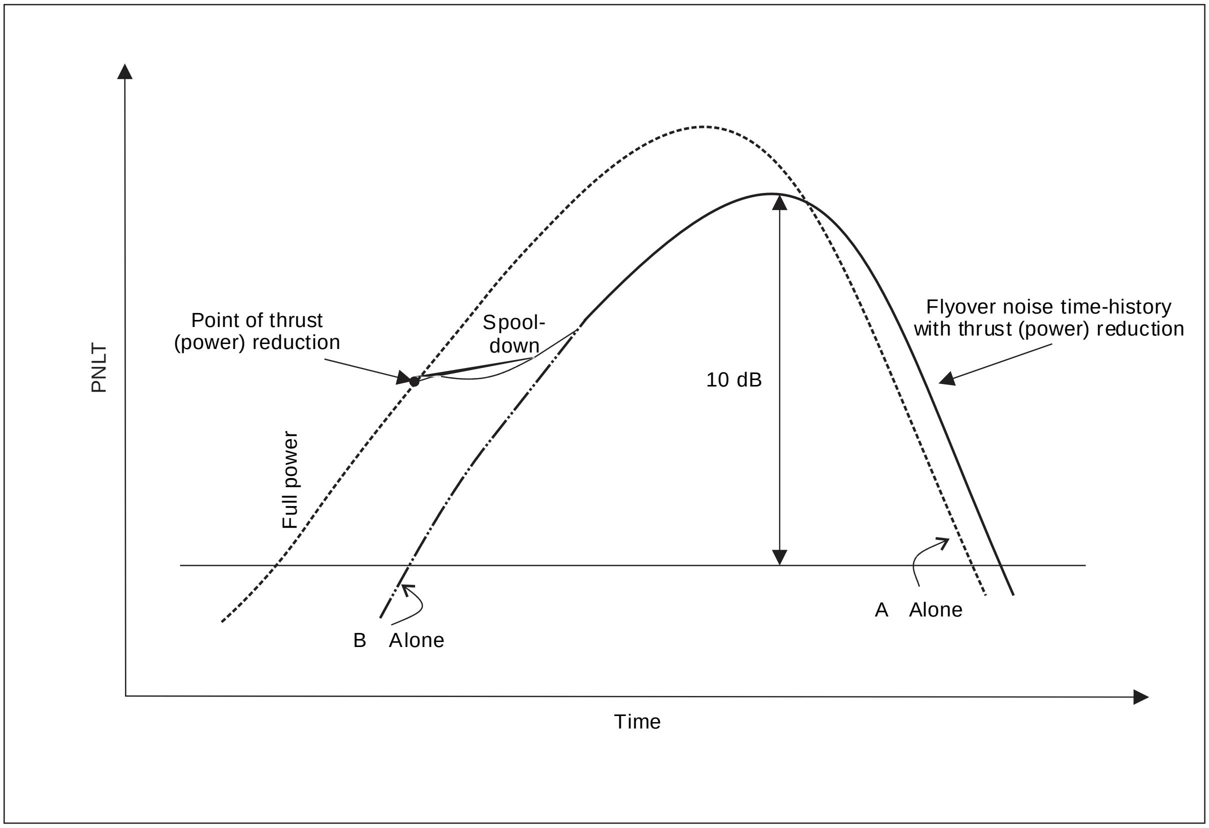


Figure 4-14. Take-off noise time history

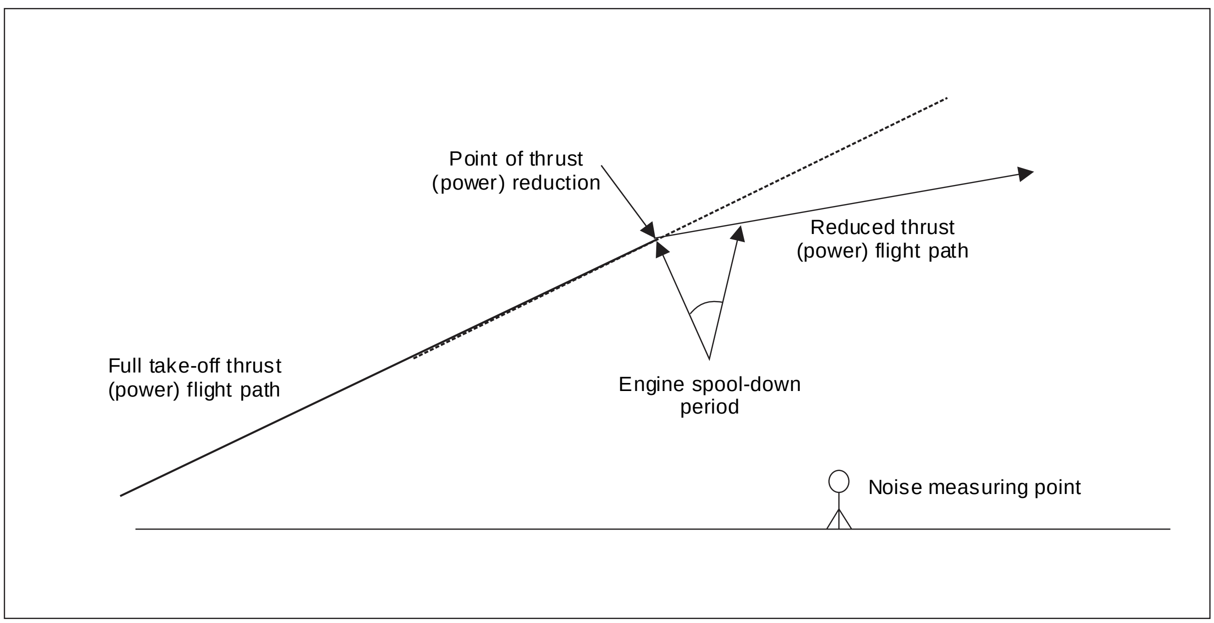


Figure 4-15. Take-off flight path over flyover measuring point with thrust (power) reduction

4) *Flight path*

Figure 4-17 illustrates the envelope for flight path tolerance within which the flight crew should fly between points C and F. Certificating authorities have permitted a ±20 per cent tolerance in overhead test height and a ±10° lateral tolerance relative to the extended runway centre line. These tolerances permit the applicant to conduct testing during most wind conditions with minimal risk of retesting being required due to off-target flight paths. In conjunction with the climb gradient and approach angle, these flight path deviation limitations define the take-off "flight path" through which the aircraft is to fly during and throughout the noise measurements (i.e. throughout the 10 dB-down period).

During flyover and lateral noise measurements, the extended centre line is not visible and it may be more difficult to conduct flight within the approved flight path, especially during conditions with anomalous winds aloft. Several methods have been devised to assist and provide direction to the flight crew in order to stay within the required flight path envelope. Indicators located in the aeroplane cockpit can provide flight path direction and indicate deviations from the extended runway centre line. Transmissions from the aeroplane position-indicating system (e.g. microwave position system, precision DMU or DGPS) can also provide useful inputs.

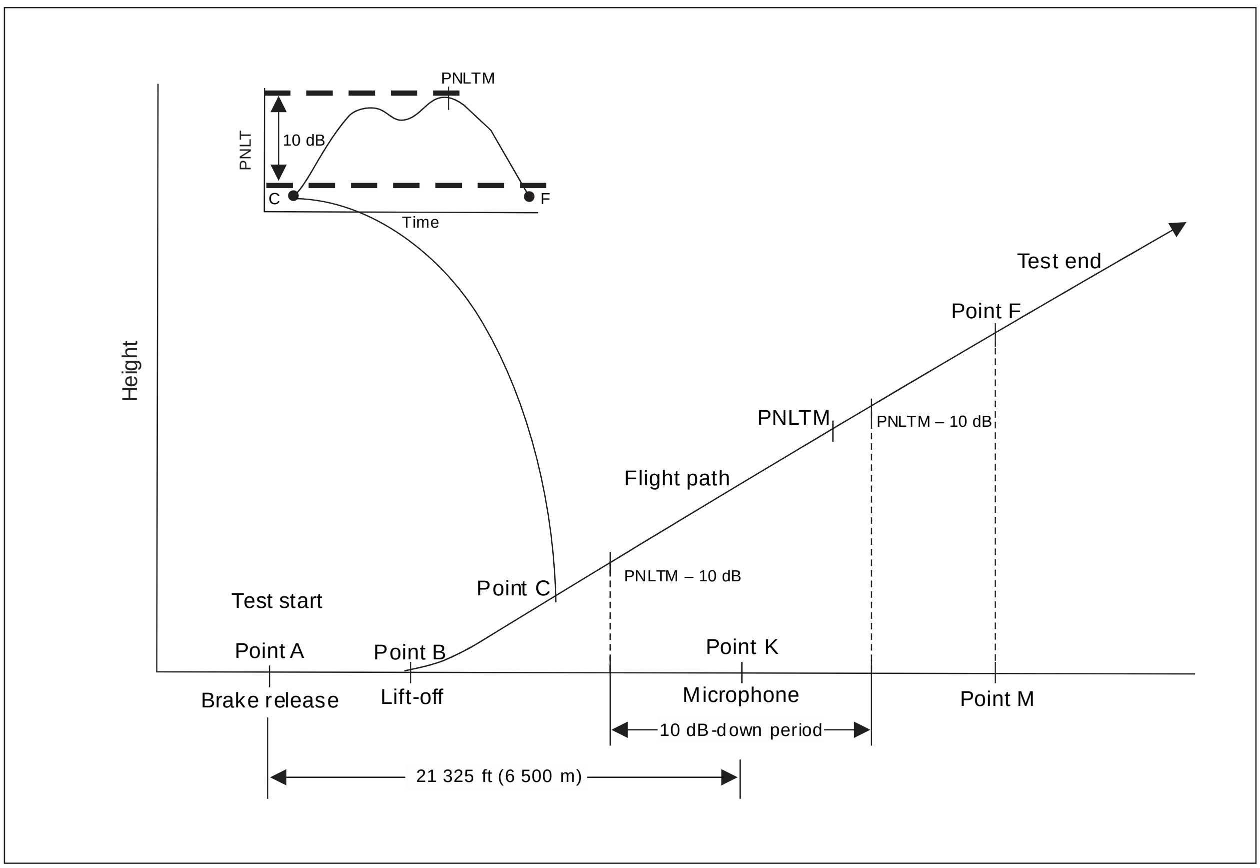


Figure 4-16. Normal full thrust (power) take-of

AMC A2 8.1.1.2
[Take-off test procedures]

1) *Target test conditions*

Target test conditions are established for each noise measurement. These target conditions specify the flight procedure, aerodynamic configuration to be selected, aeroplane mass, engine thrust (power), airspeed and, at the closest point of approach to the noise measurement point, aeroplane height. Regarding choice of target airspeeds and variation in test masses, the possible combinations of these test elements may affect the aeroplane angle-of-attack or aeroplane height and, therefore, possibly the aeroplane noise generation or propagation geometry (see 4.2.1.1.2.1 for guidance on the choice of target airspeeds and variation in test masses).

2) *Flight test procedures*

Before the start of noise testing the certificating authority should approve flight path tolerances (see GM A2 8.1.1.2). Except when take-offs with thrust (power) reduction are being demonstrated, the engine thrust (power), aeroplane flight path and aerodynamic configuration should be kept constant between points C and F (see Figure 4-17) during each approved certification flight test.

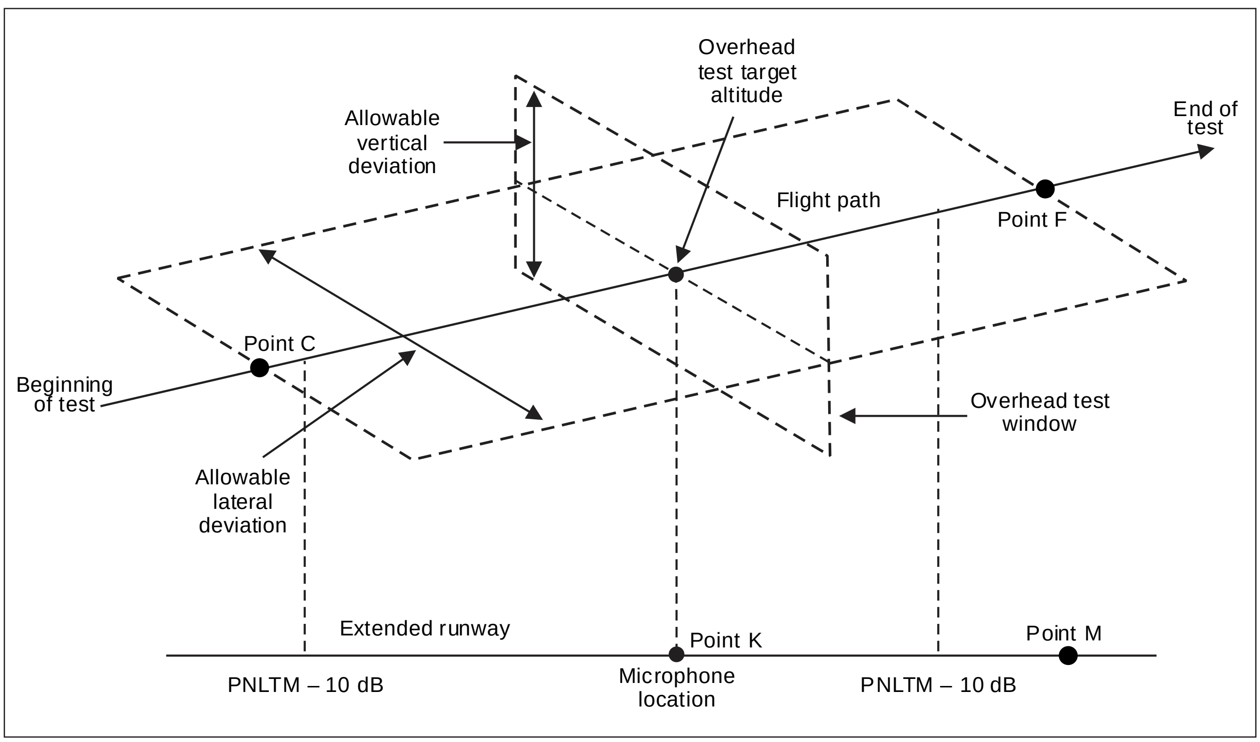


Figure 4-17. Take-off flight path tolerances

3) *Invalid test data*

Noise measurements obtained when the aeroplane flies outside the approved flight path envelope between points C and F (see Figure 4-17) during a noise certification test are considered invalid, and the noise measurement is to be repeated.

GM A2 8.1.1.3
[Approach test configuration]

1) *Approach tests*

Figure 4-18 depicts the reference approach flight test configuration for noise certification testing of aeroplanes. The approach angle (steady glide angle) for this condition is 3° ± 0.5°, and the target aeroplane height vertically above the noise measurement point is 120 m (394 ft). Maximum PNLT may occur before or after the approach noise measurement point.

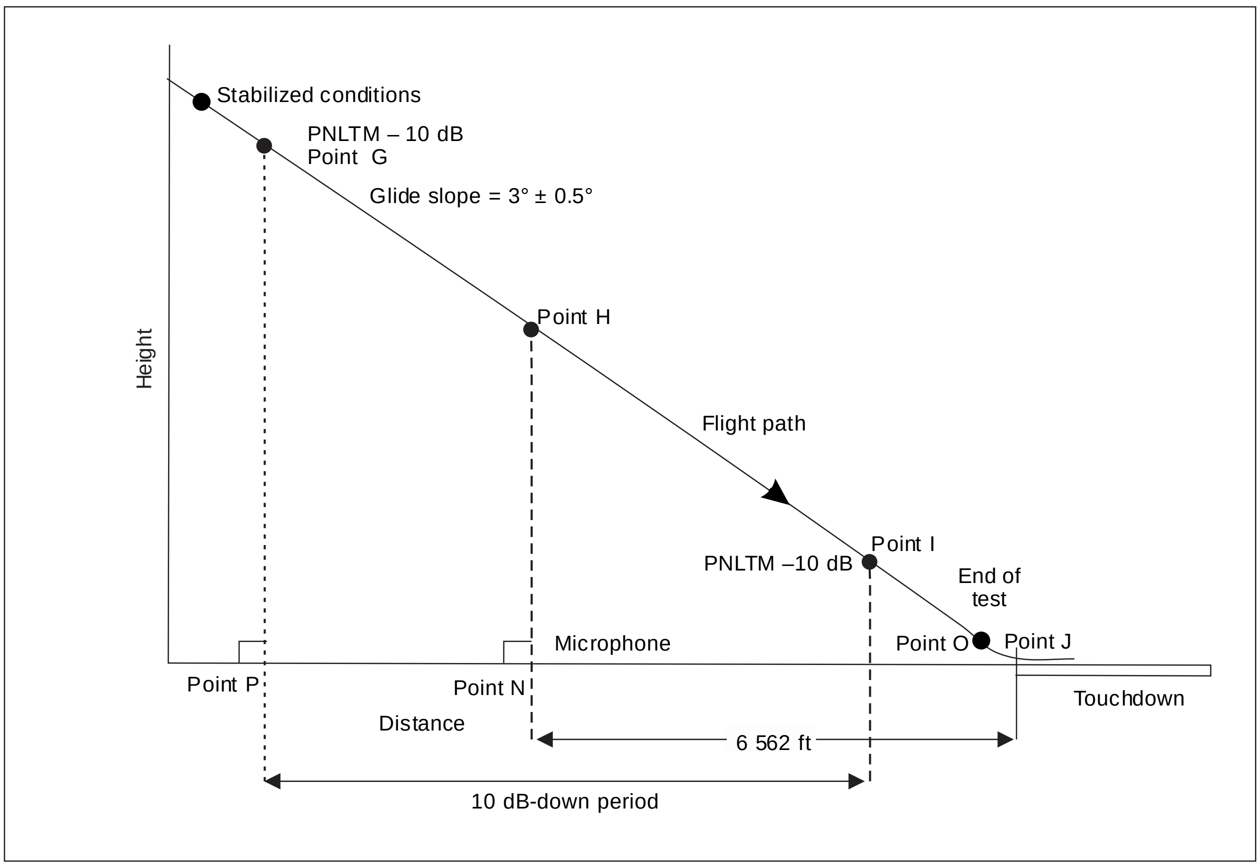


Figure 4-18. Approach with full landing

2) *Flight path deviations*

Approved height and centre line deviations along the extended runway approach flight path (see Figure 4-19) define an approved flight path envelope within which the flight crew should fly between points G and I. In cases where the flight crew has a clear view of the airport runway during the approach, it is common for the crew to consistently fly within the approved flight path envelope. Therefore, the approved centre line and height deviations for approach conditions may be smaller than during take-off conditions.

AMC A2 8.1.1.3
[Approach test procedures]

1) *Target test conditions*

Target test conditions should be established for each noise measurement. These specify the selected aerodynamic configuration, system operation, aeroplane mass, flight procedure (such as complete landings or flight path intercepts) height, thrust (power) and airspeed during each noise measurement. The applicant is required to select the approved airworthiness configuration for the approach noise certification that produces the highest noise level (i.e. the most critical from the standpoint of noise). The airspeed requirement for subsonic jet aeroplanes is V_{REF} +19 km/h (V_{REF} + 10 kt). This airspeed is kept constant, within ±3.0 per cent, throughout the 10 dB-down period (i.e. between points G and I in Figure 4-19). The aeroplane configuration (e.g. flap setting, air conditioning and/or APU system operation) is to remain constant during the noise measurement period. Airspeed variations are measured in terms of IAS as determined by the pilot's airspeed indicator.

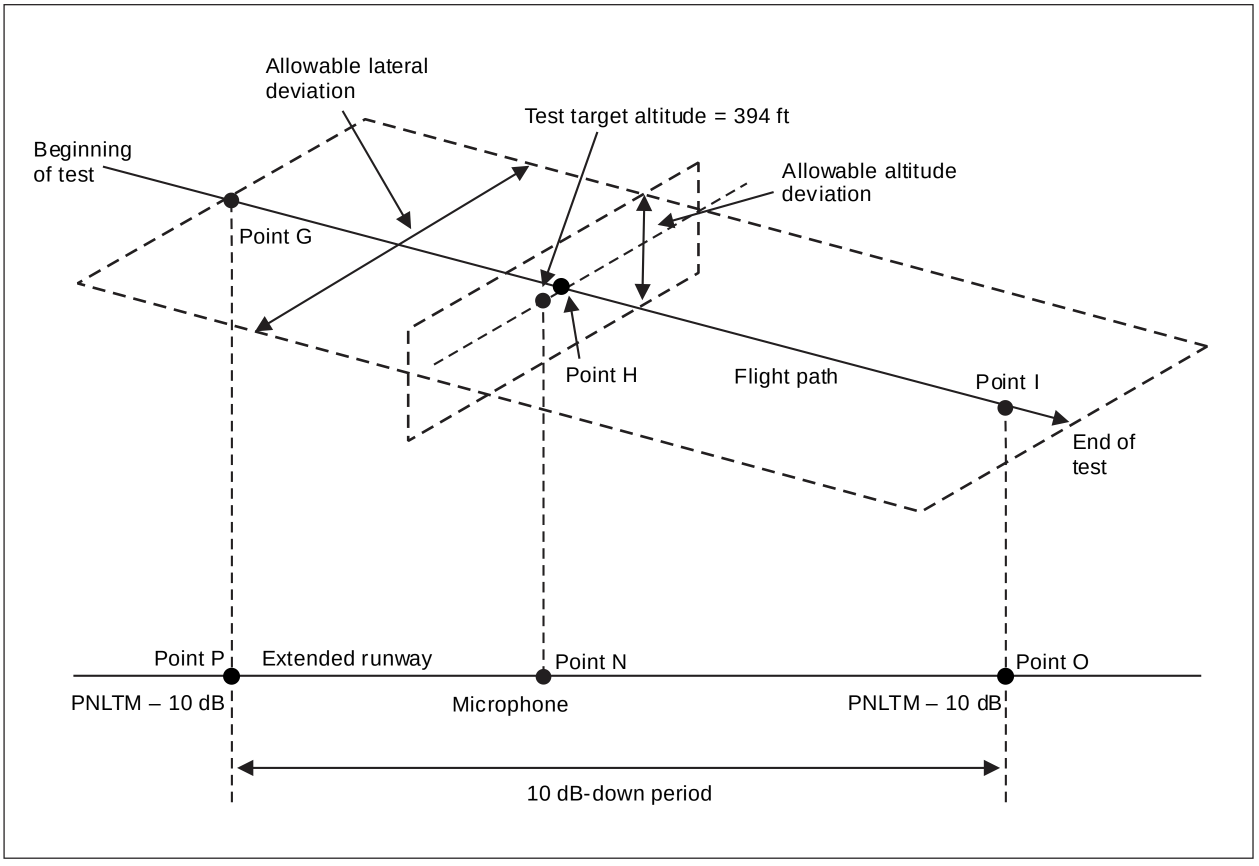


Figure 4-19. Approach flight path tolerances

2) *Engine idle trim*

For engines where the idle trim may affect the inter-compressor bleed valve schedule during the approach condition, the engine in-flight idle trim should be adjusted to the highest engine speed setting permitted by the engine manufacturer and consistent with airworthiness requirements. The engine may also provide ground idle trim adjustment, but the trim that needs adjustment is that which is operable during flight. In-flight idle trim may be adjusted to improve engine acceleration characteristics to satisfy airworthiness compliance. The higher idle trim will cause the highest engine speed, and hence idle thrust (power), which results in a greater aeroplane angle-of-attack and will result in the loudest approach noise required for certification. The applicant is to make those adjustments necessary to satisfy the airworthiness regulations. This idle trim adjustment may affect the performance or evaluation of approach NPD testing.

3) *Internal compressor bleed adjustment*

The internal compressor bleed operation, sometimes referred to as the surge bleed valve (SBV) operation, should be adjusted within the engine manufacturer's specification to represent reference conditions as closely as possible. Most turbojet engines are equipped with internal compressor bleed systems. The internal compressor bleed operates to reduce the possibility of internal engine surges during rapid throttle movements. Some jet engines have overboard bleed systems that generate high noise levels. These systems normally operate above in-flight idle and do not present a problem unless the applicant chooses to prepare an NPD database and the thrust (power) settings higher than in-flight idle. The applicant is responsible for substantiating that either the internal compressor bleed operation does not affect the reference EPNL values during noise certification reference conditions, or the data contains the effects of the internal compressor bleed operation.

4) *Invalid test data*

Noise measurements obtained when the aircraft flies outside the approved flight path envelope between points G and I are invalid, and the noise measurement shall be repeated.

GM A2 8.1.1.1
[Lateral noise measurements]

1) *Measured lateral noise levels*

Measured lateral noise levels may not be the same at symmetrical noise measurement points even when the data are adjusted for aeroplane position for flight directly over the extended runway centre line. This non-symmetrical nature of measured sideline noise is primarily attributable to the direction of engine or propeller rotation. Because of inlet shielding, jet-powered aeroplanes may exhibit 1 to 2 dB differences in lateral noise levels. Turbo-propeller-powered aeroplanes can exhibit differences in lateral noise levels in excess of 6 dB. Due to their inherent lateral noise asymmetry, 3.3.2.2 of Chapter 3 of the Annex specifies that, for propeller-driven aeroplanes, simultaneous measurements be made at each and every test noise measurement point at its symmetrical position on the opposite side of the flight track.

GM A2 8.4
[Integrated procedure adjustments]

1) *Integrated procedure adjustments*

Section 4.3.1.1 provides details of an approved integrated adjustment method when the aeroplane is operated at stabilized flight path and thrust (power) conditions during the noise measurement period. Measured and reference flight paths are illustrated in Figure A2-10 of Appendix 2 of the Annex.

GM A2 8.3.1.2
[Sound emission angles]

1) *Sound emission angles*

For the integrated method, each one-half-second noise data record will define a separate sound emission angle. This angle will then define the location of each data record along the reference flight path. The distance between consecutive data records along the reference flight path, divided by the reference path speed, provides the time interval between reference data records. The reference duration of each of these data records can be determined by obtaining the average of the two intervals between the adjacent data records. This may be different than 0.5 seconds. Paragraph 4.3.1.1.4 provides methods for time interval computations using the integrated method.

4.2 EQUIVALENT PROCEDURES INFORMATION

4.2.1 Subsonic jet aeroplanes

4.2.1.1 ***Flight test procedures***

The following methods have been used to provide equivalent results to the procedures for jet aeroplanes described in Chapters 3 and 4 of the Annex.

4.2.1.1.1 *Flight path intercepts*

Flight path intercept procedures, in lieu of full take-off and/or landing profiles described in 8.1.1 of Appendix 2 of the Annex, have been used to meet the demonstration requirements for noise certification. The intercept procedures have also been used in the implementation of the generalized flight test procedures described in 4.2.1.1.2. The use of intercepts eliminates the need for actual take-offs and landings, with significant cost and operational advantages at high gross mass, and substantially reduces the test time required. Site selection problems are reduced, and the shorter test period provides a higher probability of stable meteorological conditions during testing. Aeroplane wear and fuel consumption are reduced, while greater consistency and quality of noise data are obtained.

4.2.1.1.1.1 For take-off

Part a) of Figure 4-20 illustrates a typical take-off profile. The aeroplane is initially stabilized in level flight at point A and continues to point B where take-off power is selected and a steady climb is initiated. The steady climb condition is achieved at point C, intercepting the reference take-off flight path and continuing to the end of the noise certification take-off flight path. Point D is the theoretical take-off rotation point used in establishing the reference flight path. If thrust (power) reduction is employed, point E is the point of application of thrust (power) reduction, and point F is the end of the noise certification take-off flight path. The distance TN is the distance over which the position of the aeroplane is measured and synchronized with the noise measurement at point K.

4.2.1.1.1.2 For approach

The aeroplane usually follows the planned flight trajectory while maintaining a constant configuration and power until there is no influence on the noise levels within 10 dB of the PNLTM. The aeroplane then carries out a go-around rather than continuing the landing (see part b) of Figure 4-20).

For the development of the NPD data for the approach case, the speed and approach angle constraints imposed by 3.6.3, 3.7.5, 4.5 and 4.6 of Chapters 3 and 4 of the Annex cannot be satisfied over the typical ranges of thrust (power) needed. For the approach case, a steady speed of V_{REF} + 19 km/h (V_{REF} + 10 kt) should be maintained to within ±9 km/h (±5 kt), and the height over the microphone should be 120 ± 30 m (394 ± 100 ft). Within these constraints the test approach angle at the test thrust (power) should be that resulting from the test aircraft conditions (i.e. mass, configuration, speed and thrust (power)).

The flight profiles should be consistent with the test requirements of the Annex over a distance that corresponds at least to noise levels that are 10 dB below the PNLTM (i.e. throughout the 10 dB-down period) obtained at the measurement points during the demonstration.

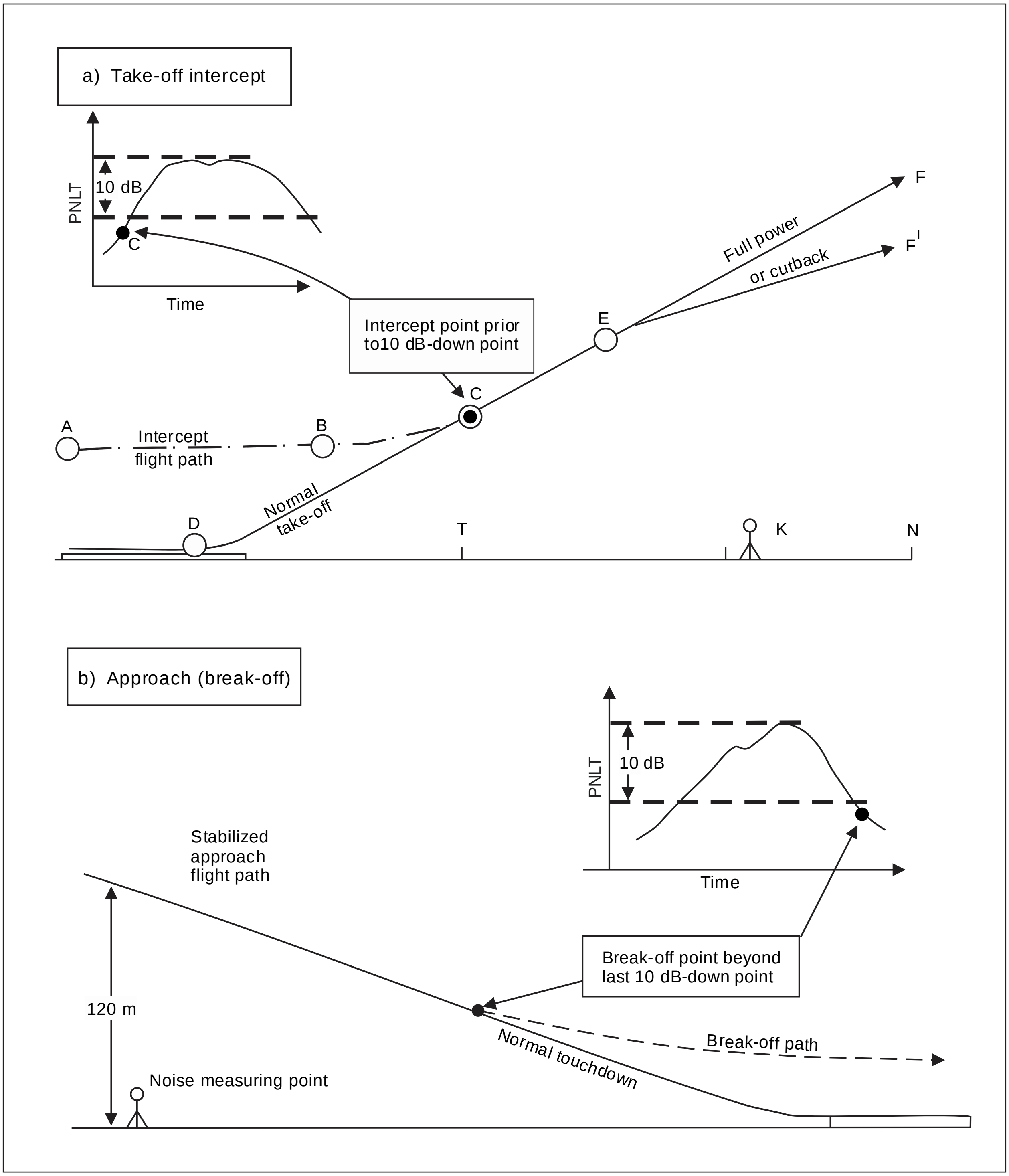


Figure 4-20. Flight path intercept procedures

4.2.1.1.2 *Generalized flight test procedures*

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

4.2.1.1.2.1 For derivation of noise-power-distance (NPD) data

For a range of thrust (power) covering full take-off and reduced thrust (power), the aeroplane is flown past lateral and under-flight-path microphones according to either the take-off procedures defined in 3.6.2 and 4.5 of Chapters 3 and 4 of the Annex or, more typically, the equivalent flight path intercept procedures described above in 4.2.1.1.1. Target test conditions are established for each sound measurement. These target test conditions define the flight procedure, the aerodynamic configuration to be selected, aeroplane mass, power, airspeed and the height at the closest point of approach to the measurement location. Regarding choice of target airspeeds and variation in test masses, 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 masses if the tests are conducted at take-off reference airspeed appropriate for each test mass. For example, if the appropriate take-off reference airspeed for the aeroplane is V_2 + 15 kt, then by setting the target airspeed at the V_2 + 15 kt appropriate for each test mass, while the actual airspeed will vary according to each test mass, the aeroplane test angle-of-attack will remain approximately constant. Alternatively, for many aeroplanes the aeroplane attitude remains approximately at the attitude associated with the take-off reference airspeed corresponding to the maximum take-off mass. Review of these potential aeroplane sensitivities may dictate the choice of target airspeeds and/or test masses 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 10 dB-down period.

A sufficient number of noise measurements are made in order to establish noise-power curves at a given distance for both lateral and flyover cases These curves are extended, either by calculation or by the use of additional flight test data to cover a range of distances, to form the generalized noise database for use in the noise certification of the "flight datum" and derived versions of the aeroplane type and are often referred to as NPD plots (see Figure 4-21). If over any portion of the range for the NPD plot, the criteria for calculating the EPNL given in 8.2.3 of Appendix 2 of the Annex requires the use of the integrated procedure, then this procedure shall be used for the whole NPD plot. The 90 per cent confidence intervals about the mean lines are constructed through the data (see 3.5).

Note.— The same techniques may be used to develop NPD plots that are appropriate for deriving approach noise levels by flying over an under-flight-path microphone for a range of approach powers, using the speed and aeroplane configuration given in 3.6.3 and 4.5 of Chapters 3 and 4 of the Annex or, more typically, the flight test procedures described in 4.2.1.1.1.2.

The availability of flight test data for use in data adjustment (e.g. speed and height) should be considered in test planning, as such availability may limit the extent to which a derived version may be certificated without further flight testing, especially where the effects of airspeed on source noise levels become significant. The effects of high altitude test-site location on jet source noise levels should also be considered in test planning. High altitude test-site locations have been approved under conditions specified in 4.3.2.3, provided that jet source noise adjustments are applied to the noise data. The correction method described in 4.3.2.3 has been approved for this purpose.

Flyover, lateral and approach noise measurements should be corrected to the reference speed and atmospheric conditions over a range of distances in accordance with the procedures described in Appendix 2 of the Annex. NPD plots can then be constructed from the adjusted EPNL, power and distances. These plots present the EPNL values for a range of distance and engine noise performance parameters.

The parameters are usually the corrected low pressure rotor speed $(N_1/\sqrt{\theta_{T2}})$ or the corrected net thrust (F_N/δ_{amb}) (see Figure 4-21), where:

— N_1 is the actual low pressure rotor speed;

— θ_{T2} is the ratio of the absolute static temperature of the air at the height of the aeroplane to the absolute temperature of the air for an ISA at mean sea level (i.e. 288.15 K);

— F_N is the actual engine net thrust (power) per engine; and

— δ_{amb} is the ratio of the 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).

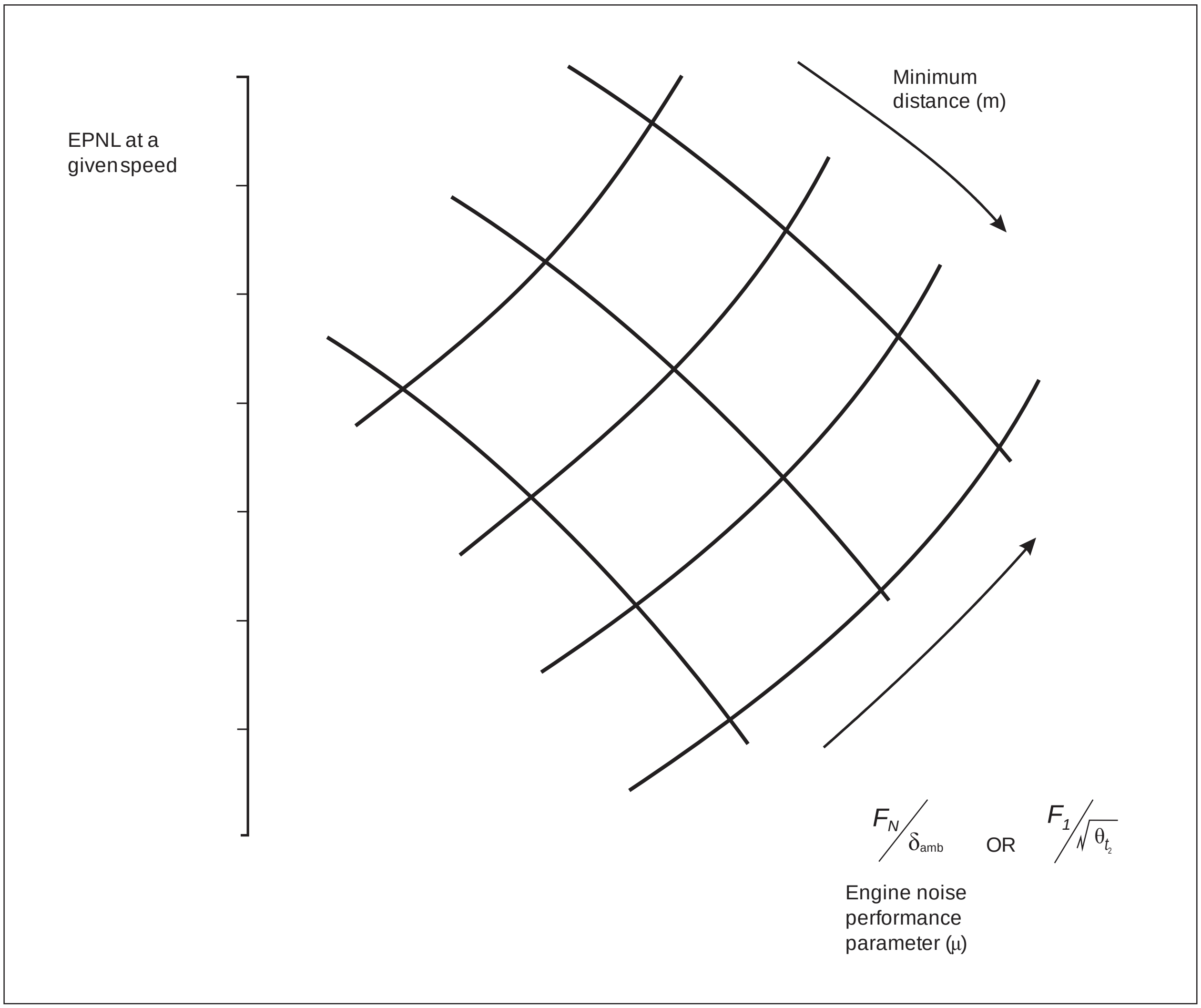


Figure 4-21. Form of noise-power-distance (NPD) plot for jet-powered aeroplanes

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

4.2.1.1.2.2 For flight test procedures for determination of changes in aeroplane certification noise levels

Noise level changes determined by comparison of flight test data for different configurations of an aeroplane type have been used to establish certification noise levels of newly derived versions by reference to the noise levels of the "flight datum" aeroplane. These noise level changes are added to or subtracted from the noise levels obtained from individual flights of the "flight datum" aeroplane. Confidence intervals of new data are statistically combined with the "flight datum" data to develop overall confidence intervals (see 3.5).

4.2.1.1.3 *Determination of the lateral certification noise levels*

The lateral full-power reference noise measurement point for jet-powered aeroplanes is defined as the point on a line parallel to and 450 m (1 476 ft) from the runway centre line, where the noise level is a maximum during take-off. Alternative procedures using two microphone stations located symmetrically on either side of the take-off reference track have proven to be effective in terms of time and cost savings. Such an arrangement avoids many of the difficulties encountered when using multiple microphone arrays along the lateral lines. The procedure consists of flying the test aeroplane at full take-off thrust (power) at several different specified heights above a track at right angles to and midway along the line joining the two microphone stations. When this procedure is used, matching data from both lateral microphones for each fly-past should be used for the lateral noise determination. Fly-pasts where data from only one microphone are available must be omitted from the determination. The following paragraphs describe this equivalent procedure for determining the lateral noise level for jet aeroplanes.

a) For aeroplanes being certificated under Chapters 3 and 4 of the Annex, two microphone locations are typically used, symmetrically placed on either side of, and 450 m (1 476 ft) from, the aeroplane reference flight track.

b) Fly-pasts are performed at constant full take-off power, configuration and airspeed as described in 3.6.2 c) and 3.6.2 d) of Chapter 3 and 4.5 of Chapter 4 of the Annex.

c) The aeroplane should be flown along a track that intersects, at right angles, the line joining the two microphones. A number of flights should be performed such that the height of the aeroplane as it crosses this line typically covers a range between 60 m and 600 m (approximately between 200 ft and 2 000 ft).

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 2 of the Annex.

e) If the adjusted noise levels show a reasonable degree of symmetry between the left and right sides, as will generally be the case for jet aeroplanes, the arithmetic average of the $EPNL_R$ values for the lateral microphone pair should be plotted against either the height of the aeroplane opposite the microphones or the average of the sound emission heights for PNLTM. A regression curve, which is typically second order, is plotted through the data points. The reported lateral EPNL at the reference condition needed for the purpose of demonstrating compliance with the applicable noise limit is the maximum value of the curve.

f) For aeroplanes for which the adjusted noise levels exhibit a marked degree of asymmetry, the $EPNL_R$ values for the left and right side should be plotted against either the height of the aeroplane opposite the microphone location or the height at the time of emission of PNLTM. Separate regression curves, which are typically second order, are plotted through the data points for the left and right sides. The reported lateral EPNL at the reference condition, $EPNL_R$, needed for the purpose of demonstrating compliance with the applicable noise limit is the maximum value of the curve midway between the left and right curves.

g) It should also be established that the confidence interval associated with the reported lateral EPNL (i.e. the maximum "regression" value of $EPNL_R$) is within the ±1.5 dB 90 per cent confidence interval specified in 5.4 of Appendix 2 of the Annex (see 3.5.2.2).

Note.— Exceptionally, and in order to obtain a curve from which a maximum value can be clearly determined, either a third order regression curve or the removal from the analysis of some outlying data points might be permitted. Applicants will be required to provide technical justification for the use of such exceptional procedures, which will be subject to the approval by the certificating authority.

Certification lateral noise levels have also been determined by using multiple pairs of laterally opposed microphones rather than only one pair. In this case the microphones must be sufficiently spaced along the lateral line to ensure that the noise levels measured at each microphone are statistically independent. A sufficient number of data points, resulting from a minimum of six runs, must be obtained in order to adequately define the maximum lateral $EPNL_R$ value and provide an acceptable 90 per cent confidence interval.

Lateral noise measurements for a range of conventionally configured aeroplanes with under-wing and/or rear-fuselage mounted engines having a bypass ratio of more than two have shown that the maximum lateral noise at full power normally occurs when the aeroplane is close to 300 m (984 ft) in height during the take-off. Based on this finding, and subject to the approval by the certificating authority, the aeroplane may be flown on a minimum of six acceptable occasions such that it passes the microphone stations at a target height of 300 m (984 ft) while staying within +100 m, -50 m (+328 ft, -164 ft) of this target height.

4.2.1.1.4 *Take-off flyover noise levels with thrust (power) reduction*

Flyover noise levels with thrust (power) reduction may also be established without making measurements during take-off with full thrust (power) followed by thrust (power) reduction (see 4.2.1.2.1 for details).

4.2.1.1.5 *Measurements at non-reference points*

In some instances test measurement points may differ from the reference measurement points specified in 3.3.1 and 4.3 of Chapters 3 and 4 of the Annex. Under these circumstances an applicant may request approval of data that have been adjusted from actual measurements in order to represent data that would have been measured at the reference noise measurement points at reference conditions. Reasons for requesting approval of such adjusted data may be:

a) to allow the use of a measurement location that is closer to the aeroplane flight path so as to improve data quality by obtaining a greater ratio of signal to background noise. Whereas 3.6.3, describes a procedure for removing the effects of background noise, the use of data collected closer to the aeroplane avoids the interpolations and extrapolations inherent in the method;

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

c) to avoid obstructions near the noise measurement points, which could influence sound measurements. When a flight path intercept technique is being used, flyover and approach noise measurement points may be relocated as necessary to avoid undesirable obstructions. Lateral noise measurement points may be relocated by distances that 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.

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 8.2.3 of Appendix 2 of the Annex and the magnitudes of the adjustments do not exceed the limitations cited in 3.7.6 and 4.6 of Chapters 3 and 4 of the Annex.

4.2.1.1.6 *Atmospheric test conditions*

Certificating authorities have found it acceptable to exceed the sound attenuation coefficient limits of 2.2.2.4.1 d) of Appendix 2 of the Annex in cases when:

a) the dew point and dry bulb temperature are measured with a device that is accurate to ±0.5°C and are used to obtain relative humidity, and when “layered” sections of the atmosphere are used to compute sound attenuation coefficients in each one-third octave band in compliance with the provisions of 2.2.2.5 of Appendix 2 of the Annex; or

b) 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.

4.2.1.1.7 *Layering equivalency*

Section 2.2.2.5 of Appendix 2 of the Annex defines the procedure for layering the atmosphere and determining the sound attenuation coefficients to be used in the adjustment of aircraft noise levels. The procedure requires that the atmosphere from the ground to at least the height of the aeroplane shall be divided into layers of 30 m (100 ft) depth. Subject to the approval by the certificating authority, the applicant may use layers of more or less, and not necessarily equal, depth. The applicant should demonstrate that the layering procedure being proposed is equivalent to the procedure defined in the Annex.

4.2.1.2 ***Analytical procedures***

Analytical equivalent procedures rely upon available noise and performance data obtained from flight tests for the aeroplane type. Generalized relationships between noise, power and distance (see 4.2.1.1.2.1 for derivation of NPD plots) and adjustment procedures for speed changes in accordance with the methods of Appendix 2 of the Annex 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 4.2.1.1.2.

4.2.1.2.1 *Flyover noise levels with thrust (power) reduction*

Flyover noise levels with thrust (power) reduction may be established from the merging of PNLT versus time measurements obtained during constant power operations. As illustrated in Figure 4-22 a), the 10 dB-down PNLT noise time history recorded at the flyover point may contain portions of both full thrust (power) and reduced thrust (power) noise time-histories. As long as these noise time-histories, the average engine spool-down thrust (power) characteristics, and the aeroplane flight path during this period (see Figure 4-22 b)), which includes the transition from full to reduced thrust (power), are known, the flyover noise level may be computed.

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

Note 1.— The selection of the height of an aeroplane within the reference flight path for initiation of thrust (power) reduction should take into account both the “average engine” spool-down time and a 1.0-second delay for flight crew recognition and response prior to movement of the throttles to the reduced thrust (power) position.

Note 2.— To ensure that the full thrust (power) portion of the noise-time history does not intrude upon the 10 dB-down noise levels, $\underset{\textit{After cutback}}{\mathrm{PNLTM}} - \underset{\textit{Before cutback}}{\mathrm{PNLT}} \geq 10.5\,\mathrm{dB}$.

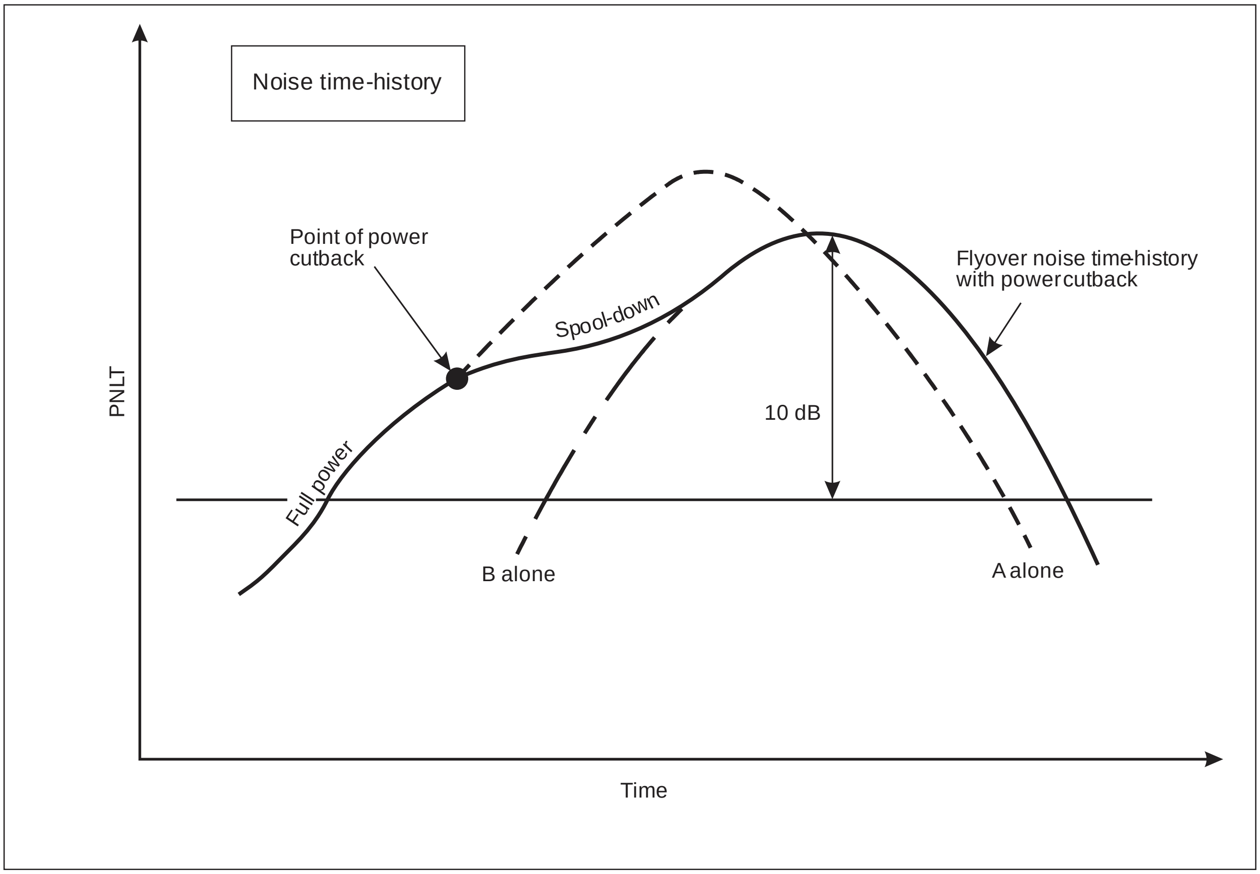


Figure 4-22 a). Computation of cutback take-off noise level from constant power tests

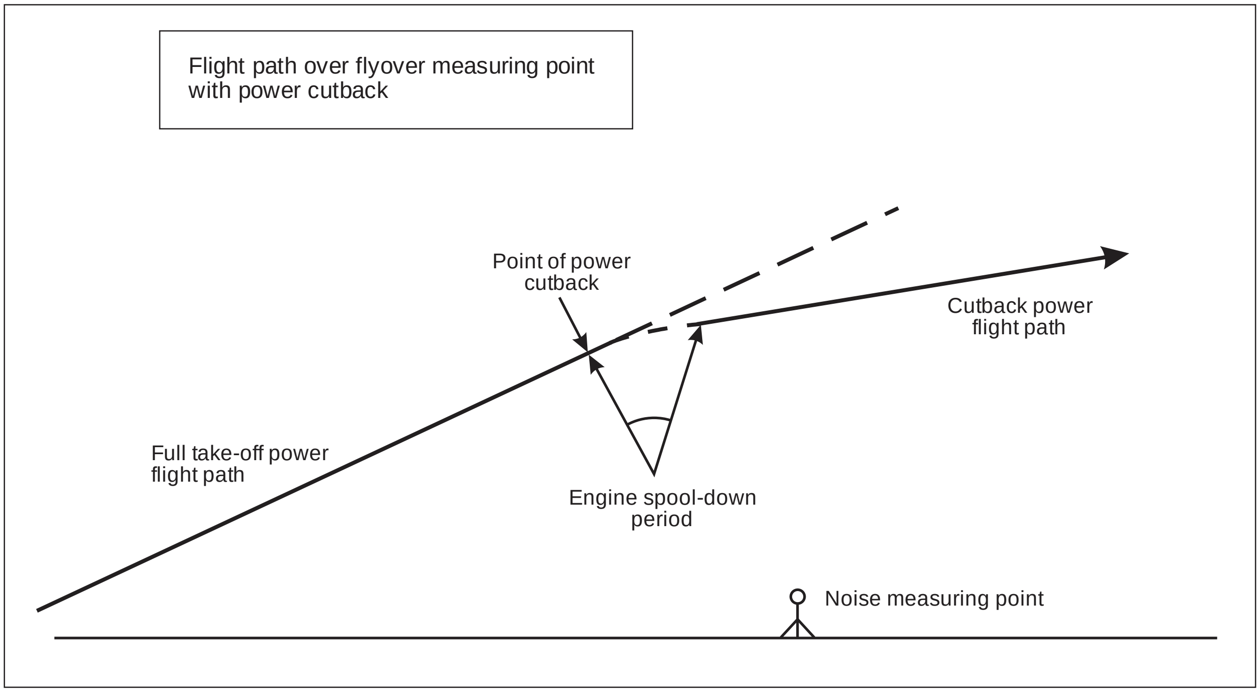


Figure 4-22 b). Computation of reduced thrust take-off noise level from constant thrust tests

4.2.1.2.2 *Equivalent procedures based upon analytical methods*

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

a) changes to the originally certificated take-off or landing mass, which in turn lead to changes in the distance between the aeroplane and the microphone and/or reduced thrust (power) for the take-off case, and changes to the approach power. In this case the NPD data may be used to determine the certification noise 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 EPNL remains essentially unchanged and a simple extrapolation of the NPD curves can be made. Among the items that should be considered in extending the NPD are:

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

 2) aeroplane/engine source noise characteristics and behaviour;

 3) engine cycle changes; and

 4) quality of data to be extrapolated;

c) aeroplane engine and nacelle configuration and acoustical treatment changes, usually leading to changes in the values of $EPNL_R$ of less than 1 dB;

Note 1.— It should however be ensured that new noise sources are not introduced by modifications made to the aeroplane, engine or nacelles. A validated analytical noise model approved by the certificating authority may be used to derive predictions of noise increments. The analysis may consist of modelling each aeroplane component noise source and projecting the sources to flight conditions in a manner similar to the static test procedure described in 4.2.1.3. 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 parameters that relate 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 4.2.1.3, an $EPNL_R$ value representative of flight conditions should be computed by adjusting aeroplane component noise sources for forward speed effects and for the number of engines and shielding, reconstructing the total noise spectra, and projecting the total noise spectra to flight conditions by accounting for propagation effects. The effect of changes in acoustic treatment, such as nacelle lining, may be modelled and applied to the appropriate component noise sources. The computation of the total noise increments, the development of the changed version NPD, and the evaluation of the changed version $EPNL_R$ values should be made by using the procedures described in 4.2.1.3.4. Guidance material on confidence interval computations is provided in 3.5.

Note 2.— Some engine or aircraft design changes may change the nature of the noise signature of the engine or aircraft and prevent an ordered extension of noise data. In which case static engine noise tests may not provide adequate proof that an extension of the noise database is valid. Changes that may cause transition of the fan tip velocity to supersonic, interaction of the mid-span fan shrouds or stator vanes, choking of the fan exit guide vanes or primary compressor entrance, operation of the surge bleed valve, an increase in the inlet bypass airflow or a change in aircraft configuration interaction are examples of such changes.

d) airframe design changes (e.g. changes in fuselage length, flap configuration and engine installation) that could indirectly affect noise levels because of an effect on aeroplane performance (e.g. increased drag).

Note 1.— 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.

Note 2.— In these cases care should be exercised to ensure that the airframe design changes do not introduce significant new noise sources or modify existing source generation or radiation characteristics. In such instances the magnitude of such effects may have to be established by test.

4.2.1.2.2.1 Equivalent procedure for calculating the certification noise levels of mass variants of a given aeroplane type

Section 1.2 of Chapter 1 of Annex 16 specifies that "Noise certification shall be granted or validated by the State of Registry of an aircraft on the basis of satisfactory evidence that the aircraft complies with the requirements that are at least equal to the applicable Standards in this Annex". The lateral, flyover and approach noise levels and their 90 per cent confidence intervals for the mass variants of a given aeroplane/engine model and acoustic configuration are typically derived from generalized NPD curves, based on the information in noise certification reports and supporting documentation, and in conjunction with certificated aerodynamic performance data for the aeroplane, as approved by the certification authorities.

Some aeroplane manufacturers have used the noise level information initially certificated for several mass variants to demonstrate that when the basic aeroplane performance parameters (e.g. V_2 and V_{REF}) vary in a linear manner over a range of certificated take-off or approach mass, the resulting noise (EPNL) versus mass relationship can be shown to be linear in that range as well. When this situation is demonstrated by the applicant and, subject to the approval by the certificating authority, the applicant may derive the certification noise levels of additional mass variants using linear interpolation between certificated points calculated according to the procedures defined in the Annex. The confidence interval for the interpolated mass is then to be established in a process that utilizes the polynomial regression models that had been used by the applicant to develop the NPD.

The following steps describe an acceptable process for the calculation of confidence intervals for the interpolated masses (see Figure 4-23):

a) Step 0: Required input: EPNL versus engine parameter data points, polynomial regression lines and confidence intervals available for baseline lower and baseline higher certified masses.

b) Step1: Interpolate the additional mass variant EPNL between lower and higher mass variants EPNL.

c) Step2: Build an interpolated polynomial regression line for the additional mass variant by interpolating the polynomial regression coefficients between those of the lower and higher masses. Note that all three polynomial regressions must be of the same order.

d) Step3: Derive the reference engine parameter associated to the interpolated noise levels of the additional mass variant by identifying its position on the interpolated regression line (i.e. the value of the engine parameter associated with the interpolated EPNL).

e) Step4: Build the EPNL versus engine parameter data points associated to the additional mass variant by interpolating between the EPNL and engine parameter data points associated to the lower and higher mass variants respectively.

f) Step5: Calculate the confidence interval of the EPNL for the additional mass variant using standard statistical formulation described in section 3.5.2 applied to the distribution of interpolated data points around interpolated regression line obtained at steps 3 and 4.

For a given aeroplane type, equivalency of the interpolated noise level values is demonstrated when the noise levels and the associated confidence intervals are calculated and reported in a manner acceptable to the certificating authority.

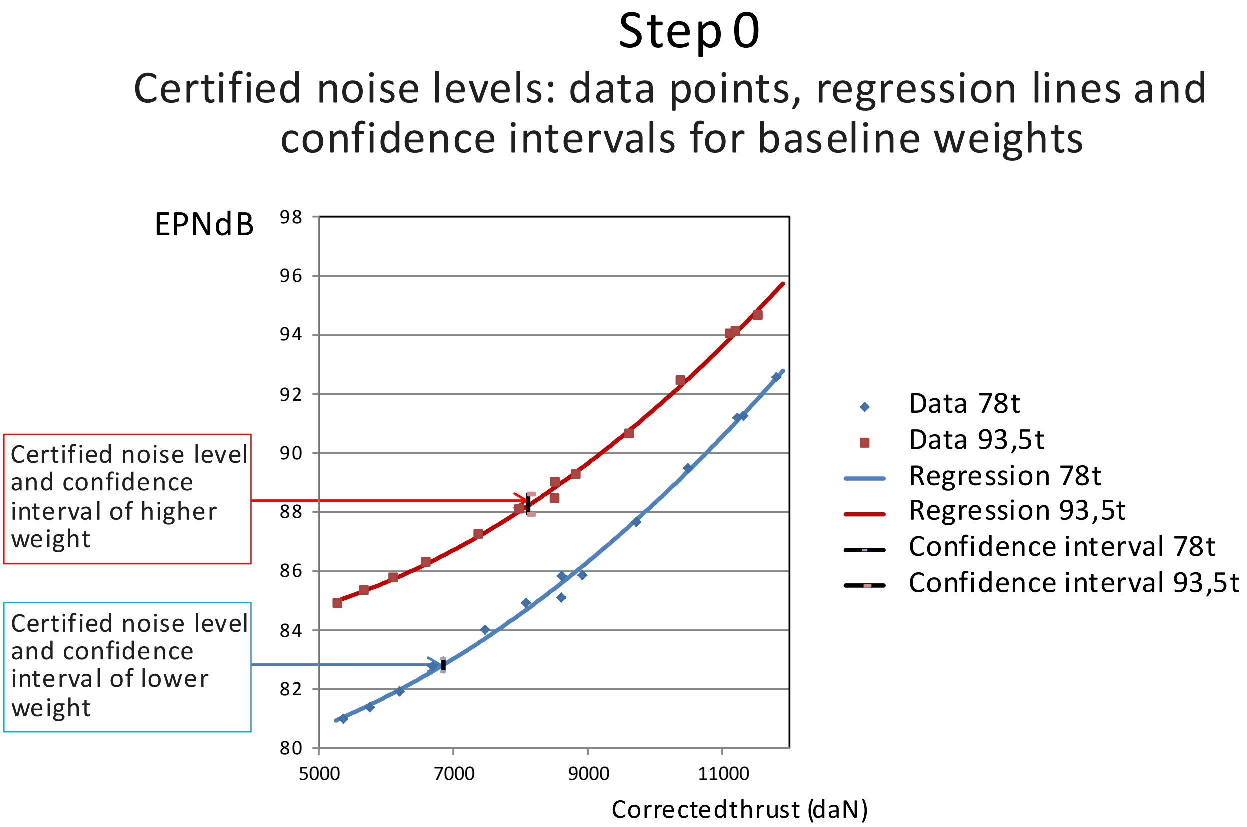


Figure 4-23 a). Calculation of confidence intervals for the interpolated masses

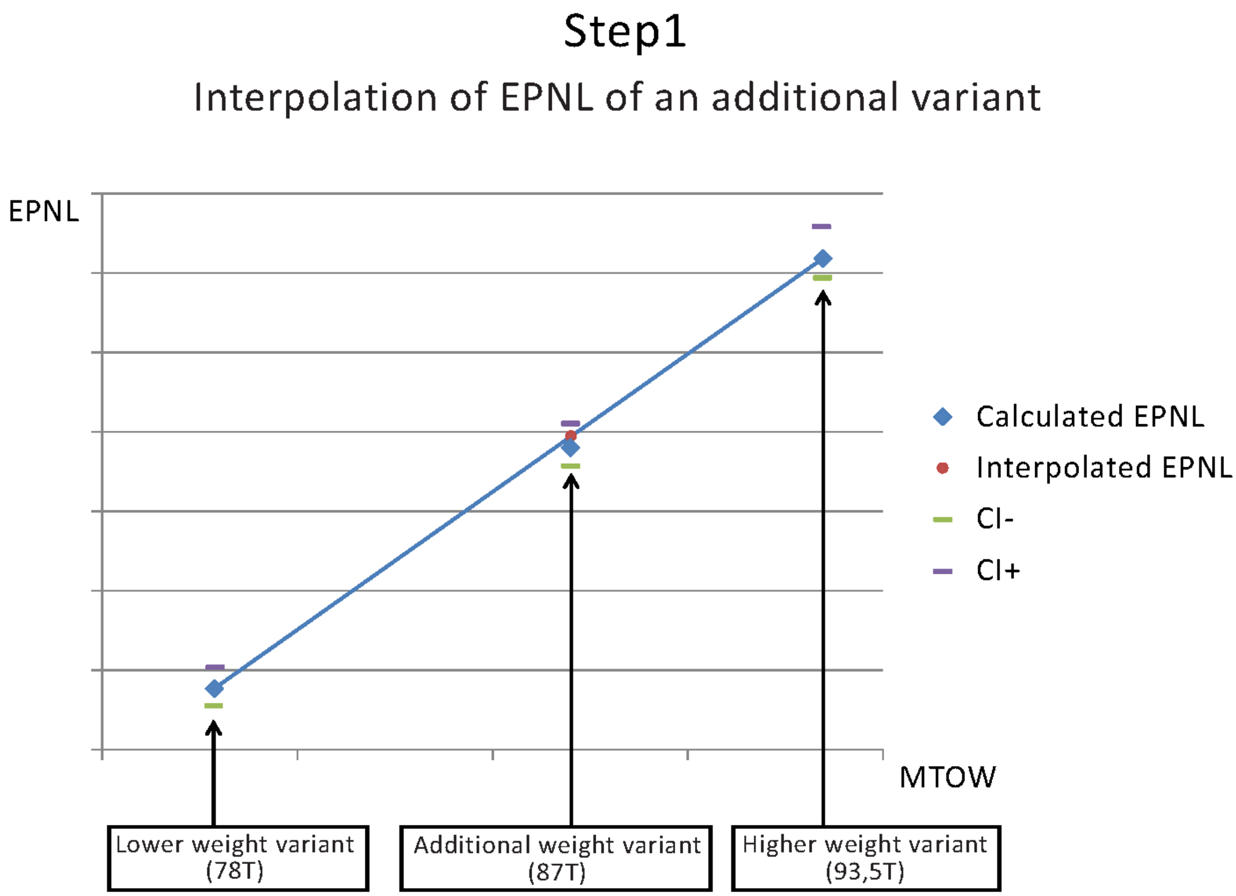


Figure 4-23 b). Calculation of confidence intervals for the interpolated masses

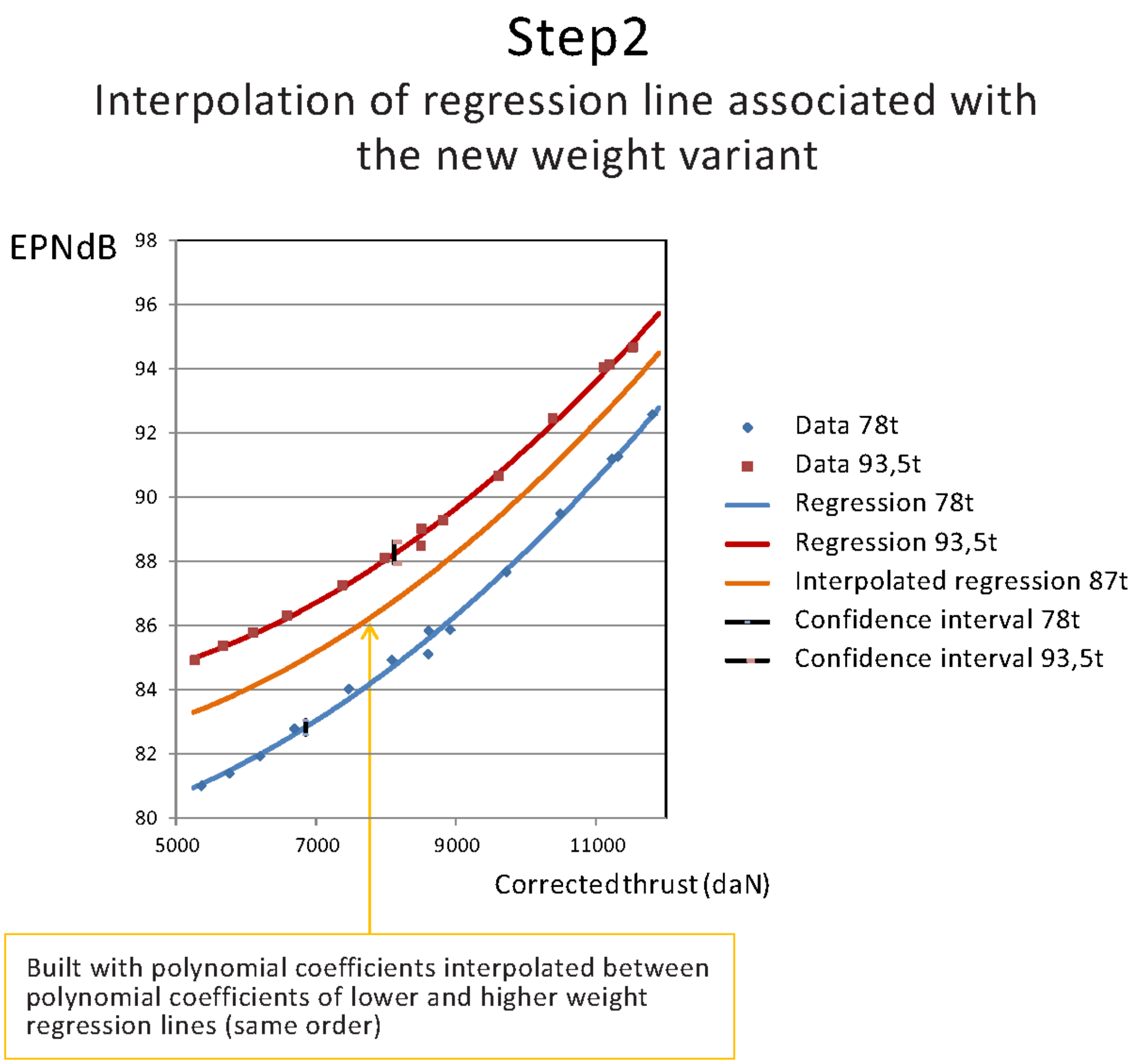


Figure 4-23 c). Calculation of confidence intervals for the interpolated masses

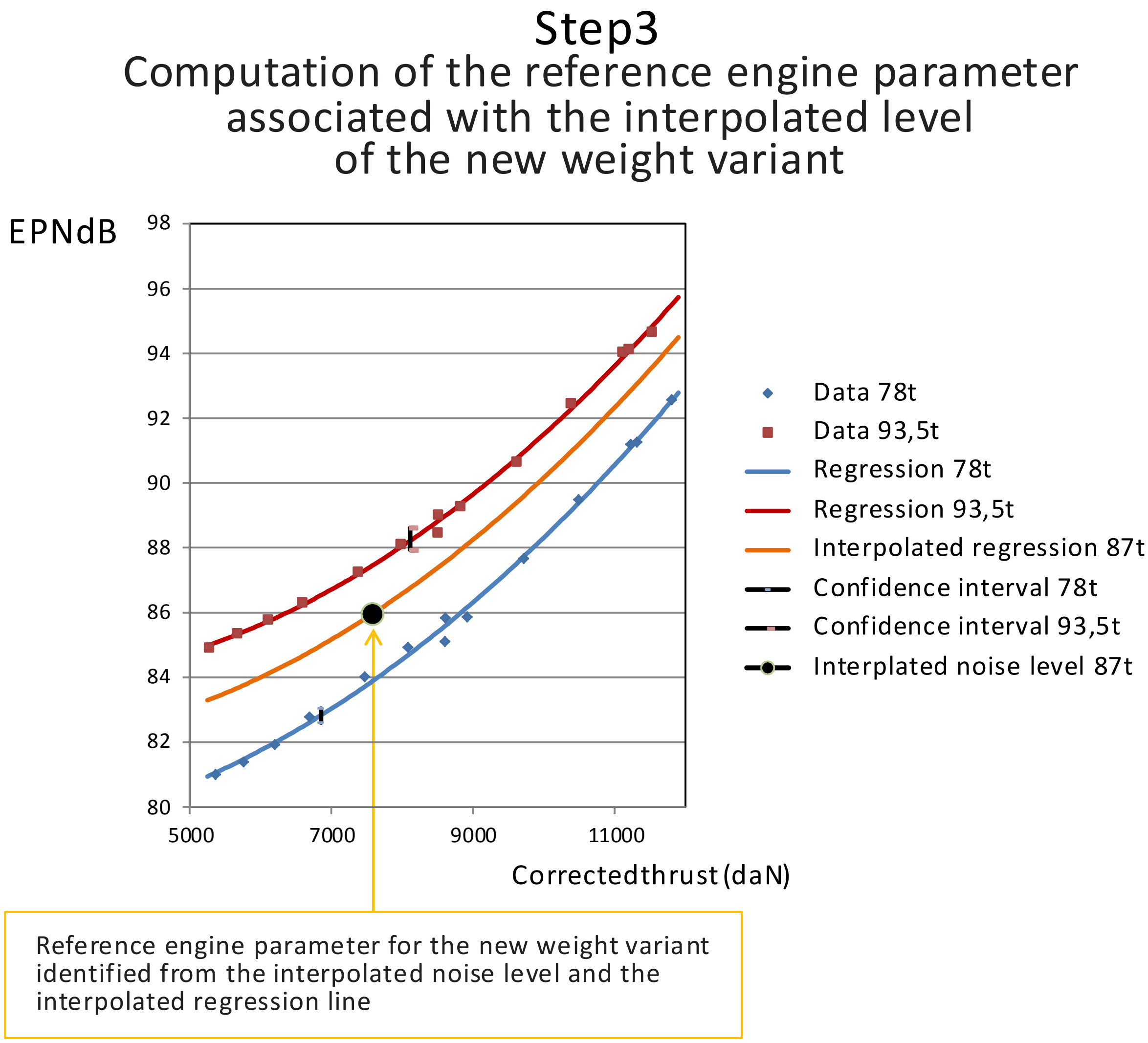


Figure 4-23 d). Calculation of confidence intervals for the interpolated masses

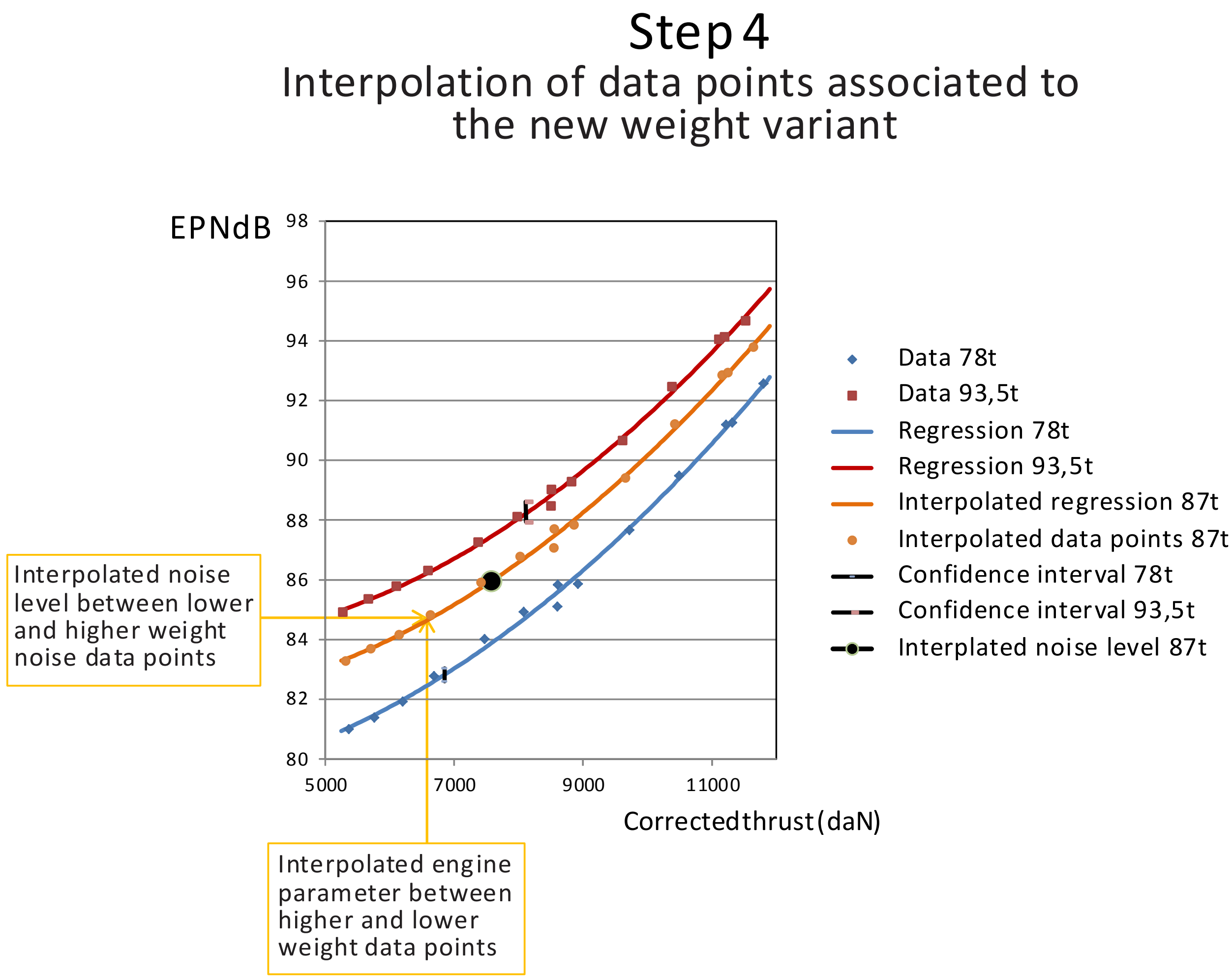


Figure 4-23 e). Calculation of confidence intervals for the interpolated masses

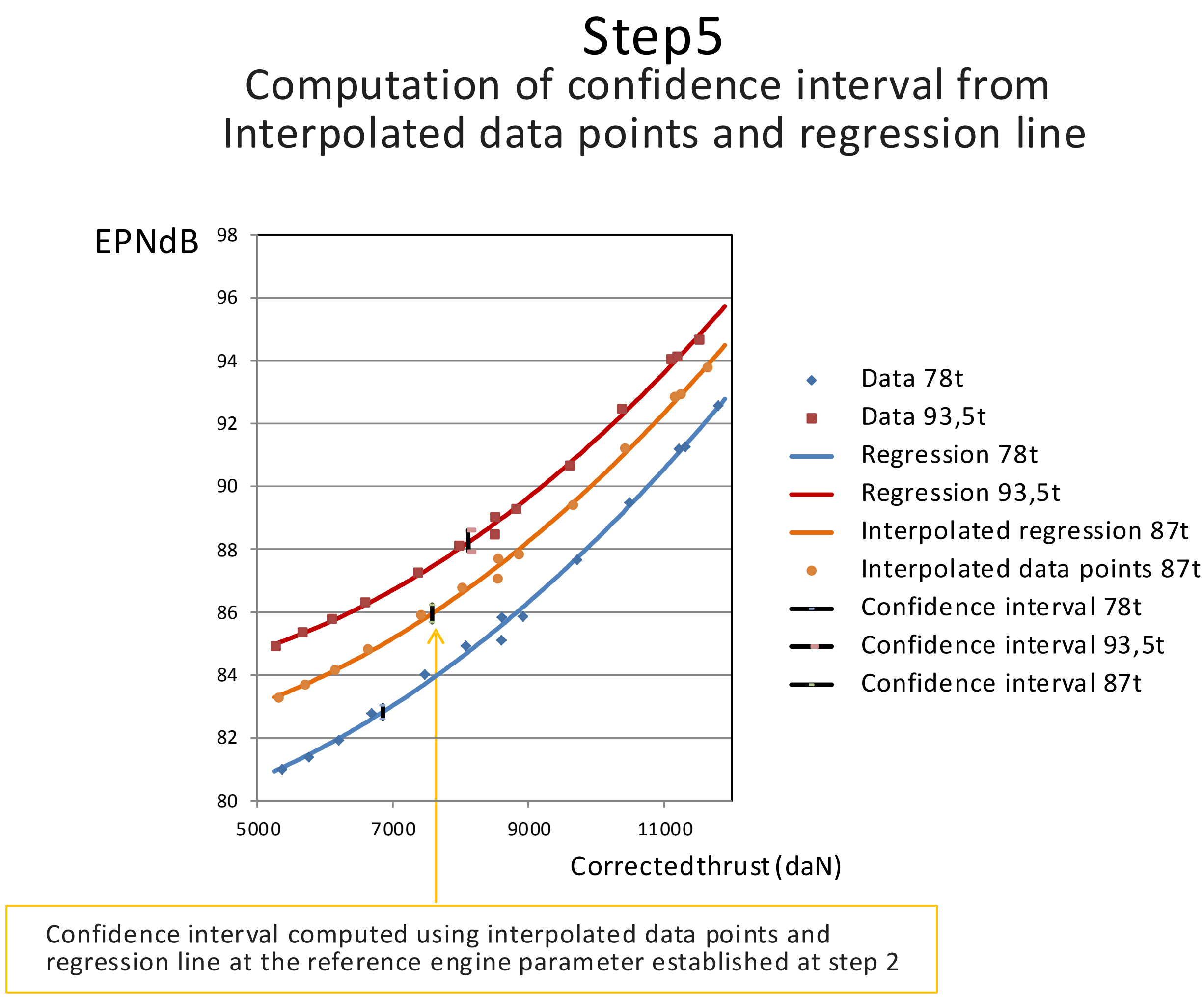


Figure 4-23 f). Calculation of confidence intervals for the interpolated masses

4.2.1.3 ***Static engine noise tests and projections to flight noise levels***

4.2.1.3.1 *General*

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

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

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

Types of static tests accepted for the purposes of demonstrating certification compliance in aeroplane development include engine noise tests. Such tests are useful for assessing the effects on the individual noise sources of mechanical and thermodynamic cycle changes to the engine. Such configuration and/or design changes often occur as engines are developed, subsequent to the initial noise certification of an aircraft, to ease production difficulties, reduce cost, improve durability, and for operational reasons.

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

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, including material changes;

d) changes to bleed valves; and

e) changes to the exhaust system.

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

4.2.1.3.2 *Limitation on the projection of static-to-flight data*

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

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

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

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

c) changes to the nacelle.

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

The recommended guideline for this limit is that the summation of the magnitudes, neglecting signs, of the noise changes for the three reference certification conditions between the “flight datum” aeroplane and the derived version at the same thrust (power) and distance for the derived version is no greater than 5 EPNdB, with a maximum of 3 EPNdB at any one of the reference conditions (see Figure 4-24). For differences greater than this, additional flight testing at conditions where noise levels are expected to change is recommended in order to establish a new flight NPD database.

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

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

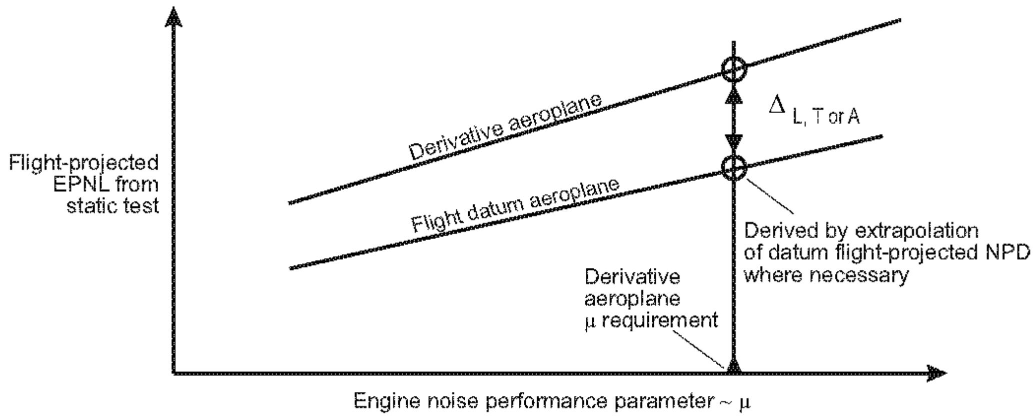
In determining the noise levels of the modified or derived version, the same analytical procedures used in the first static-to-flight calculations for the noise certification of the aeroplane type shall be used.

4.2.1.3.3 *Static engine noise test procedures*

4.2.1.3.3.1 General

Test restrictions defined for flight testing in conformity with the Annex are not necessarily appropriate for static testing. Reference 14 provides appropriate, detailed guidance for measurement of far-field sound pressure levels during static operation of gas turbine engines installed on an outdoor test stand. The following sections provide guidelines supplemental to sections on test site characteristics, data acquisition and reduction, microphone types, location and installations provided in Reference 14. These supplemental guidelines are specifically related to static engine noise testing for purposes of aeroplane noise certification.

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



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 4-24. Limitation on use of static test when no validating flight data exist

4.2.1.3.3.2 Test site characteristics

a) *Inflow control devices (ICD).* Static engine noise test data for the noise certification of an aeroplane with a change of engine to another one of a similar design should be acquired by using an approved ICD for high bypass engines (i.e. BPR > 2.0). The ICD should meet the requirements in Reference 14. The specific ICD hardware should be inspected by the certificating authority to ensure that the ICD is free from damage and contaminants that may affect its acoustic performance.

b) *ICD calibration.* An acceptable ICD calibration method is provided in Reference 14. In some cases large fluctuations in the value of the calibrations across adjacent one-third octave bands and between closely spaced angular positions of microphones can occur. These fluctuations can be related to reflection effects caused by the calibration procedure, and care must be taken to ensure that they do not introduce or suppress engine tones. This may be done by comparing EPNL computed with:

1) the ICD calibrations as measured;

2) a mean value of the calibration curves; and

3) the calibration values set to zero.

4.2.1.3.3.3 Data acquisition and reduction systems

a) *Data acquisition analysis and normalization.* Data acquisition and analysis systems used for static test and the modus operandi of the test programme may well vary according to specific test objectives. In general they should conform to those outlined in Reference 14.

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 measurement systems and test procedures described in Reference 14 or as approved by the certificating authority.

A range of static engine operating conditions should be selected to correspond to the expected maximum range of inflight engine operating conditions for the appropriate engine power setting parameter. A sufficient number of stabilized engine power settings over the desired range should be included in the test to ensure that the 90 per cent confidence intervals for values of flight-projected EPNL can be established (see 3.5.3).

Noise measurements should be normalized to consistent conditions and include 24 one-third octave band sound pressure levels between band centre frequencies of 50 Hz to 10 kHz for each measurement microphone. Before projecting the static engine data to flight conditions, the sound pressure level data should be adjusted for:

1) the frequency response characteristics of the noise measurement system; and

2) contamination by background or electrical system noise (see 3.6.3).

b) *Data system compatibility.* 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 flight test noise data samples on both systems. The systems can be considered to be compatible if the resulting differences are no greater than 0.5 EPNdB. Evaluation should be conducted at flight conditions representative of those for certification.

The use of measured static engine test noise data or pseudo-random noise signals with spectral shape and tonal content representative of turbofan engines is an acceptable alternative to the use of actual flight test noise data samples for determination of analysis system compatibility. The systems can be considered to be compatible if the resulting differences are no greater than 0.5 PNdB for an integration time of 32 seconds.

4.2.1.3.3.4 Microphone types, locations and installations

a) *Microphone locations.* Microphones should be located over an angular range sufficient to include the 10 dB-down times after projection of the static noise data to flight conditions. The general guidance in Reference 14 describing microphone locations is sufficient to ensure adequate definition of the engine noise source characteristics.

The choice of microphone location with respect to the test surface depends on the specific test objectives and the methods to be used for data normalization. Certification experience with static engine testing has been primarily limited to microphone installations near the ground or at engine centre line 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.

b) *Acoustic shadowing.* 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.

4.2.1.3.4 *Projection of static engine data to aeroplane flight conditions*

4.2.1.3.4.1 General

The static engine sound pressure level data acquired at each angular location should be analysed and normalized to account for the effects identified in the paragraphs below. They should then be projected to the same aeroplane flight conditions used in the development of the approved NPD plot.
As appropriate, the projection procedure includes the:

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 sound attenuation; and

f) flight propagation effects, including ground reflection and lateral attenuation.

To account for these effects, the measured total static noise data should be analysed to determine contributions from individual noise sources. After projection of the one-third octave band spectral data to flight conditions, EPNLs should be calculated for the revised NPD plot. Guidelines on the elements of an acceptable projection procedure are provided in this section. The process is also illustrated in Figures 4-25 and 4-26.

It is not intended that the procedure illustrated in Figures 4-25 and 4-26 should be exclusive. There are several options, depending upon the nature of the powerplant noise sources and the relevance of individual noise sources to the EPNL of the aeroplane. The method presented does however specify the main features that should be considered in the computational procedure.

It is also not necessary that the computations illustrated in Figures 4-25 and 4-26 should always be carried out in the order specified. There are interrelations between the various steps in the procedure that depend on the particular form of the computation being followed. Hence the most efficient manner of structuring the computation cannot always be predetermined.

There are several engine installation effects that 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 that are not present on the "flight datum" aeroplane. Far-field noise directivity patterns (i.e. 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.

4.2.1.3.4.2 Normalization to reference conditions

The analysed one-third octave band sound pressure level static test data should be normalized to free-field reference atmospheric conditions specified in 3.6.1.5 of Chapter 3 of the Annex. This adjustment can be applied only with knowledge of the total spectra being the summation of all the noise source spectra computed as described in the following paragraphs. The required adjustments include:

a) *Sound attenuation due to atmospheric absorption.* Adjustments to account for the acoustical reference-day sound attenuation are defined in Reference 17. In the event that minor differences in coefficient values are found in Reference 17 between equations, tables or graphs, the equations should be used. The sound attenuation coefficients should be computed over the actual distance from the effective centre of each noise source to each microphone, as described in 4.2.1.3.4.5.

b) *Ground reflection.* Examples of methods for obtaining free-field sound pressure levels are described in References 5 and 16. 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.

4.2.1.3.4.3 Separation into broadband and tone noise

The purpose of procedures described in this section is to identify all significant tones in the spectra: first, to ensure that tones are not included in the subsequent estimation of broadband noise and, second, to enable the Doppler-shifted tones in-flight to be allocated to the correct one-third octave band at appropriate times during a simulated aeroplane flyover.

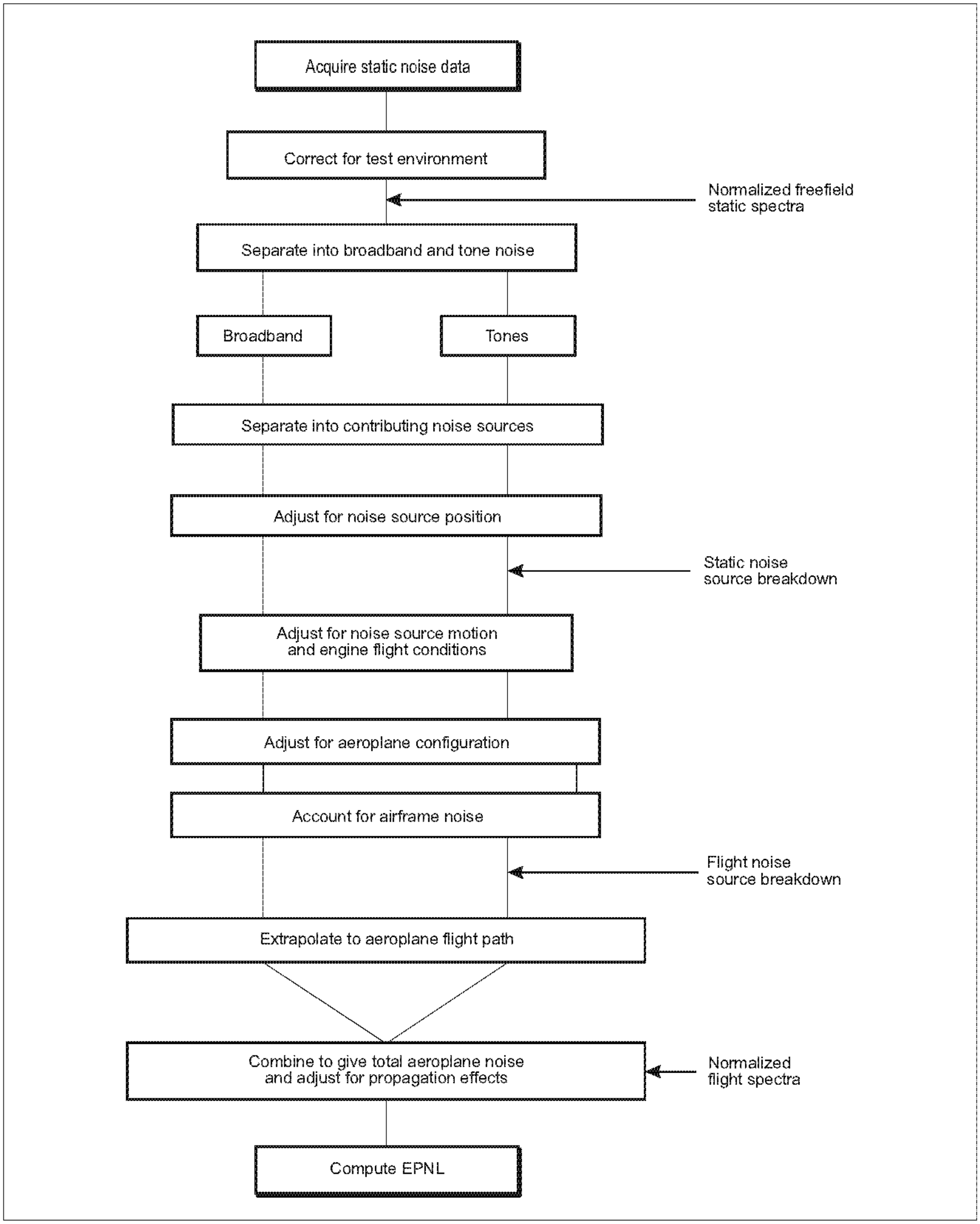


Figure 4-25. Generalized projection of static engine data to aeroplane flight conditions (refer to 4.2.1.3)

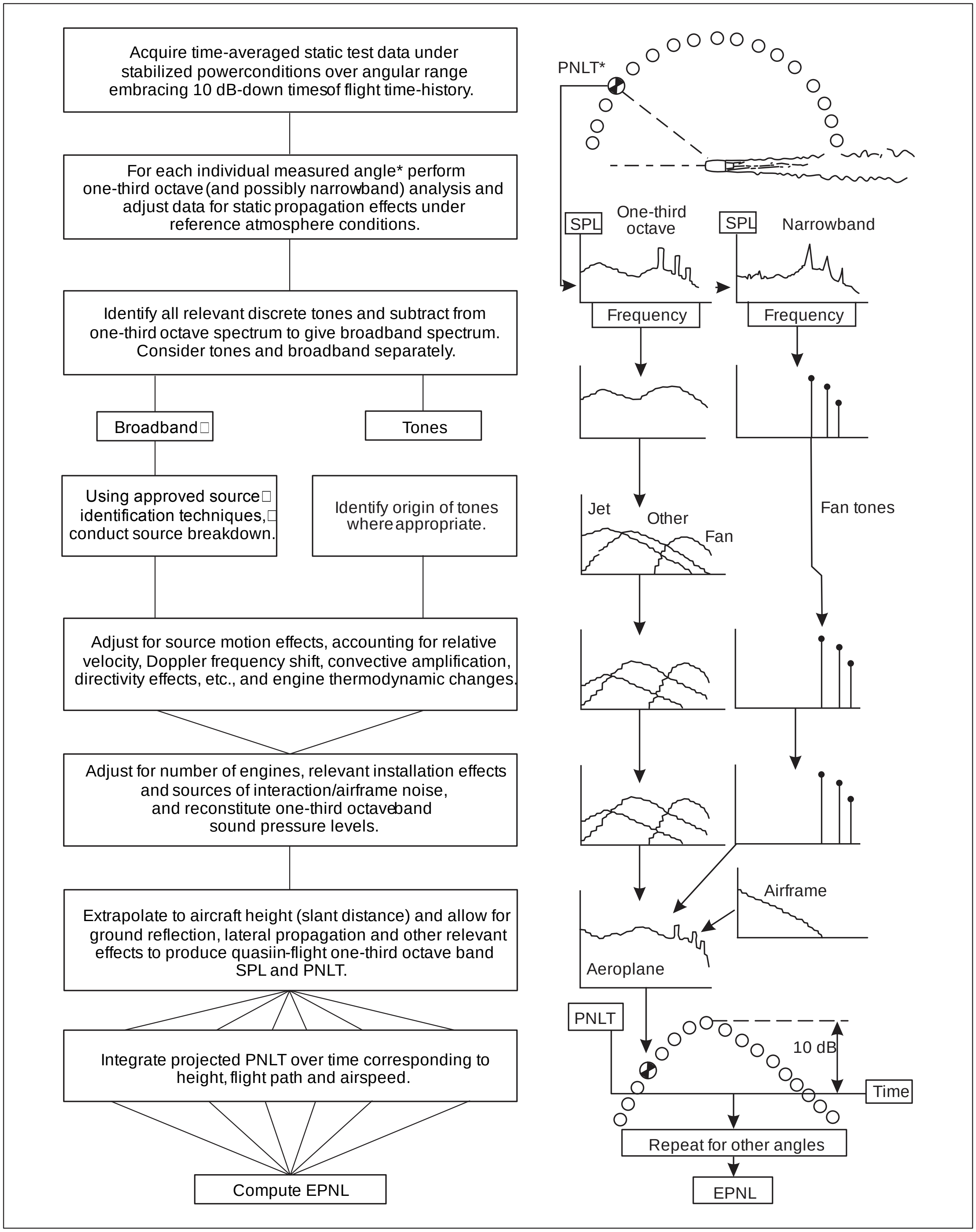


Figure 4-26. Example procedure for projection of static engine data to aeroplane flight conditions

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

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.

4.2.1.3.4.4 Separation into contributing noise sources

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

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

a) estimating the jet noise by one or more of the methods identified below; and

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

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

a) for single-stream engines with circular nozzles, the procedure detailed in Reference 13 may be used. The engine geometry however may possess features that can render this method inapplicable. Sample procedures for coaxial flow engines are provided in Reference 12;

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.

4.2.1.3.4.5 Noise source position effects

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.

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

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, in which case 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 centre line differs from the nominal angle, in which case a linear interpolation should be made to obtain data for the proper angle.

c) *Sound attenuation due to atmospheric absorption.* The difference between the true and the nominal distance between the source and the microphone alters the allowance made for sound attenuation.

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

Note.— No published standard on coaxial jet noise source distribution is currently available. An approximate distribution for a single jet is given by the following equation (see References 7 and 18):

$$x/D = (0.0575\,S + 0.0215\,S^{-2})^{-1/2}$$

where:

— S *is the Strouhal number* fD/V_j;

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

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

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

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

4.2.1.3.4.6 Engine flight conditions

Some thermodynamic conditions within an engine tested statically differ from those that exist in flight and this difference should be taken into account. Noise source strengths may be changed accordingly. Therefore, the values for key correlating parameters for component noise source generation should be based on the flight condition, and the static database should be entered at the appropriate correlating parameter value. Turbo-machinery noise levels should be based on the in-flight corrected rotor speeds $N_1/\sqrt{\theta_{T2}}$. Jet noise levels should be based on the relative jet velocities that exist at the flight condition.

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

4.2.1.3.4.7 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.

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

1) for single-stream engines with circular exhaust geometries, Reference 13 provides guidance. Additional supporting evidence however may be needed to show when jet noise is the major contributor to the noise from an engine with a more complex nozzle assembly; and

2) 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.

b) *For 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:

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

$$f_{\text{flight}} = \frac{f_{\text{static}}}{1 - \text{M} \cos \theta}$$

where:

— f_{flight} = flight frequency;

— f_{static} = static frequency;

— M = Mach number of the aeroplane; and

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

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

2) *Source amplitude modification and directivity changes.* One-third octave band sound pressure level adjustments to airframe-generated noise that results from speed changes between the datum and derivative versions provided below.

For noise generated internally within the engine (e.g. fan noise), there is no consensus of opinion on the mechanisms involved or on a unique adjustment method that accounts for the detailed source modification and sound propagation effects. If an adjustment is used, the same technique must be applied to both the flight datum and derivative configuration when establishing noise changes. In such instances the adjustment for the one-third octave band sound pressure level changes that result from the motion of the source (i.e. aeroplane) relative to the microphone may be accounted for by using the following equation:

$$SPL_{flight} = SPL_{static} - k \log (1 - M \cos \theta)$$

where:

— SPL_{flight} = flight sound pressure level;

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

— M and θ 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.

4.2.1.3.4.8 Aeroplane configuration effects

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

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

4.2.1.3.4.9 Airframe noise

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

Airframe noise for a specific configuration varies with airspeed (see Reference 6) as follows:

$$\Delta SPL_{airframe} = 50 \log (V_R / V_{TAS})$$

where:

— V_R is the approved reference airspeed for the "flight datum" aeroplane; and

— V_{TAS} is the model or measured true airspeed.

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

4.2.1.3.4.10 Aeroplane flight path considerations

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

4.2.1.3.4.11 Total noise spectra

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

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

The effects of ground reflections must be included in the estimate of free-field sound pressure levels in order to simulate the sound pressure levels that would be measured by a microphone at a height of 1.2 m (4 ft) above a natural terrain. Information in Reference 5 or 16 may be used to apply adjustments to the free-field spectra to allow for flight measurements being made at 1.2 m (4 ft). Alternatively, the ground reflection adjustment can be derived from other approved analytical or empirically derived models. Note that the Doppler adjustment for a static source at frequency, f_{static}, applies to a moving source (i.e. aeroplane) at a frequency, f_{flight}, where $f_{flight} = f_{static} / (1 - \cos \theta)$ using the same terminology as described above for the Doppler effect. This process is repeated for each measurement angle and for each engine power setting.

With regard to lateral attenuation, the information in Reference 15, applicable to the computation of lateral noise may be applied.

4.2.1.3.4.12 EPNL computations

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

4.2.1.3.4.13 Changes to noise levels

An NPD plot can be constructed from the projected static data for both the original (i.e. flight datum) and the changed configurations of the engine or nacelle tested. Comparisons of the noise versus engine thrust (power) relationships for the two configurations at the same appropriate minimum distance will determine whether or not the changed configuration resulted in a change to the noise level from an engine noise source. If there is a change in the level of source noise, a new in-flight aeroplane NPD plot can be developed by adjusting the measured original NPD plot by the amount of change indicated by the comparison of the static-projected NPD plots for the original and changed versions within the limitations specified in 4.2.1.3.2 for EPNL.

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

4.2.2 Propeller-driven aeroplanes over 8 618 kg

The procedures described in this chapter have been used as equivalent in stringency for propeller-driven aeroplanes with maximum certificated take-off mass exceeding 8 618 kg, as provided in Chapters 3 and 5 of the Annex.

4.2.2.1 ***Flight test procedures***

4.2.2.1.1 *Flight path intercept procedures*

Flight path intercept procedures, as described in 4.2.1.1.1, have been used to meet the noise certification demonstration requirements in lieu of full take-offs and/or landings.

4.2.2.1.2 *Generalized flight test procedures*

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

a) *NPD plots*

Noise data are acquired over a range of engine power settings at one or more heights. This information permits the development of generalized noise characteristics necessary for the certification of a "family" of similar aeroplanes. The procedures used are similar to those described in 4.2.1.1.2, with the exception that the NPD plots employ engine noise performance parameters, μ, of propeller helical tip Mach number, M_H, and shaft horsepower, SHP/δ_{amb}, (see Figure 4-27), where δ_{amb} is defined in 4.2.1.1.2.1.

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 ±5.5 km/h (±3 kt), as appropriate for the mass of the aeroplane during the test.

For the development of the NPD data for the approach case, the speed and approach angle constraints imposed in 3.6.3, 3.7.5, 4.5, 4.6, 5.6.3 b) and 5.7.5 of Chapters 3, 4 and 5, respectively, of the Annex cannot be satisfied over the typical range of power needed. For the approach case, a steady speed of V_{REF} + 19 km/h (V_{REF} + 10 kt) should be maintained to within ±5.5 km/h (±3 kt) and the flyover height over the microphone should be 122 ± 30 m (400 ± 100 ft). Within these constraints, the test approach angle at the test power should be that which results from the test aeroplane conditions (i.e. mass, configuration, speed and power).

b) *Noise level changes*

Comparisons are made of flyover noise test data for different developments of an aeroplane type (e.g. a change in propeller type). Such changes are used to establish certification noise levels of a newly derived version as described in 4.2.1.1.2.

4.2.2.1.3 *Determination of the lateral certification noise level*

For propeller-driven aeroplanes, Amendment 5 to the Annex introduced into Chapter 3 a full-power measurement point under the flight path as a replacement for the lateral measurement point. This section describes appropriate equivalent procedures for those aeroplanes for which the two-microphone lateral measurement method was applicable.

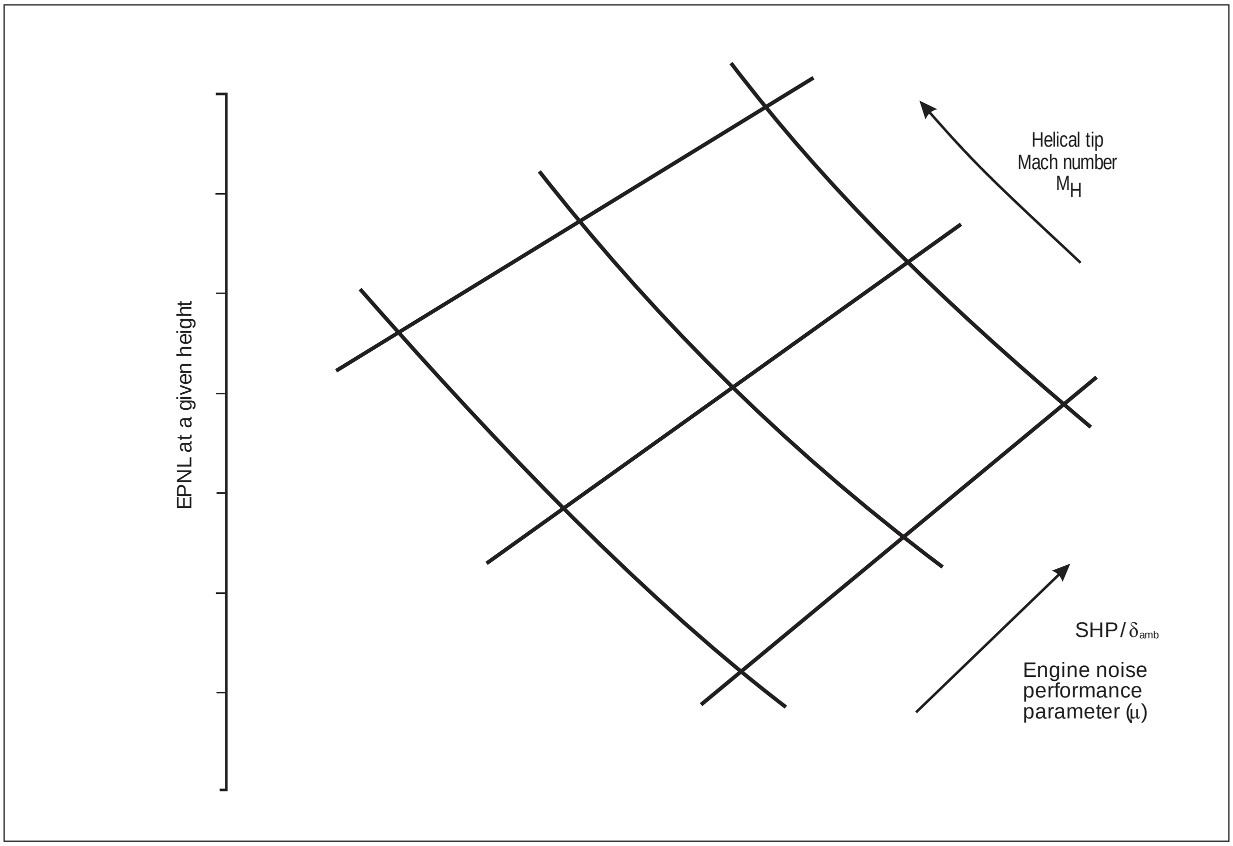


Figure 4-27. Form of noise-power-distance (NPD) plot for heavy propeller-driven aeroplanes

Determination of the lateral certification noise level employing an alternative procedure using two microphone stations located symmetrically on either side of the take-off flight path similar to that described in 4.2.1.1.3 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:

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

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

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

d) the aeroplane climbs over the reference point using take-off power, speeds and configuration as described in 3.6.2 c) and 3.6.2 d) of Chapter 3 or 5.6.2 c) and 5.6.2 d) of Chapter 5 of the Annex;

e) 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 and plotted against aeroplane height above the reference point (see Figure 4-28). 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); and

f) to ensure that the requirements of 5.4.2 of Appendix 2 of the Annex are met, the 90 per cent confidence limits should be determined in accordance with 3.5.

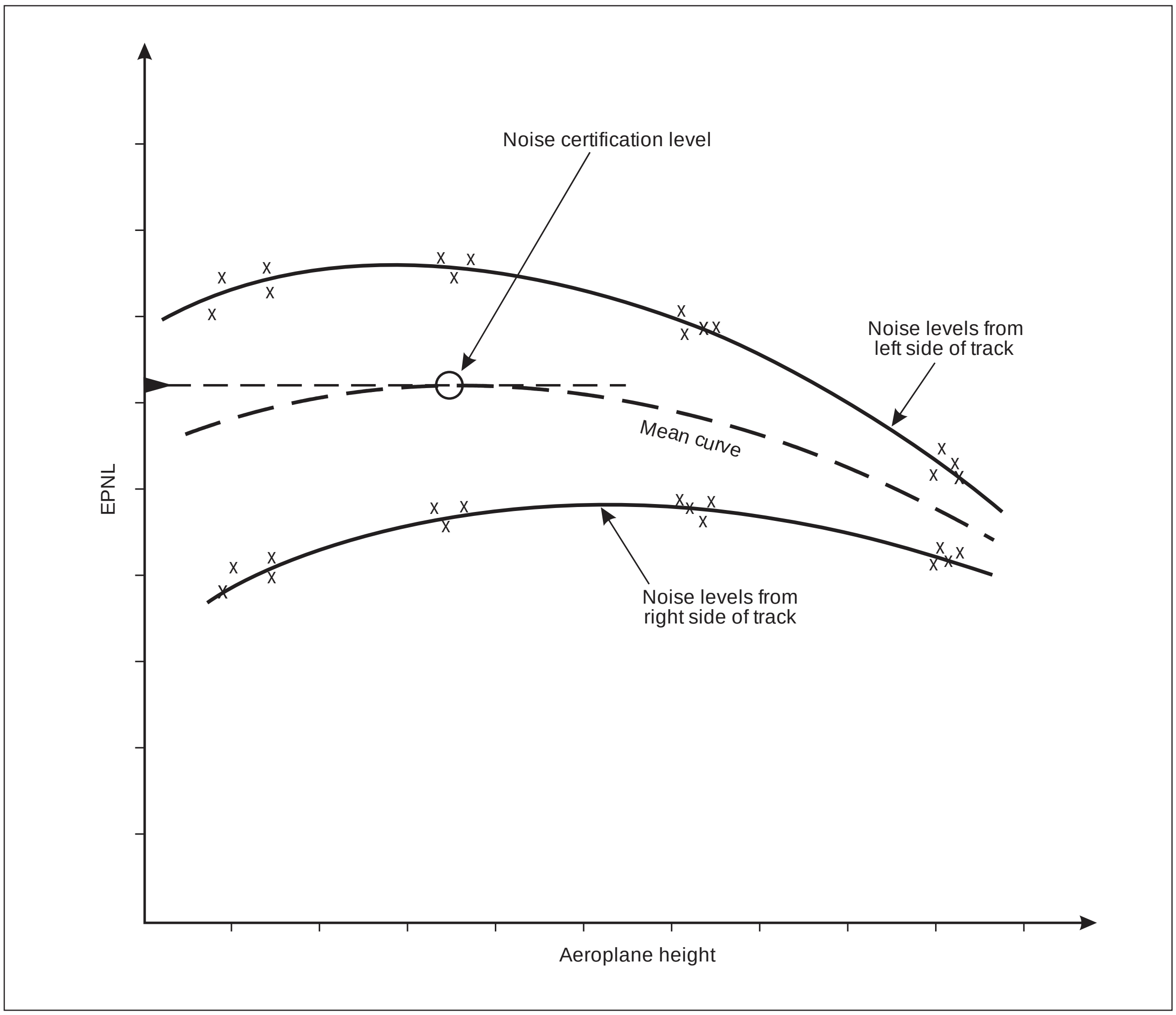


Figure 4-28. Typical lateral noise data plot for heavy propeller-driven aeroplanes

4.2.2.1.4 *Measurements at non-reference points*

In some instances, test measurement points may differ from the reference measurement points as specified in Chapters 3 and 5 of the Annex. 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 4.2.1.1.5.

Noise measurements collected closer to the test aeroplane than at the certification reference points are particularly useful for adjusting propeller noise data because they are dominated by low frequency noise. The spectra roll off rapidly at higher frequencies and are often lost in the background noise at frequencies above 5 000 Hz. Section 3.6.3, describes a procedure for background noise adjustment.

Non-reference measurement points may be used provided that measured data are adjusted to reference conditions in accordance with the requirements of section 8 of Appendix 2 of the Annex and that the magnitude of the adjustments does not exceed the limits cited in 3.7.6 of Chapter 3 and 5.7.6 of Chapter 5 of the Annex.

4.2.2.2 ***Analytical procedures***

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

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

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

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

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

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

4.2.2.3 ***Ground static testing procedures***

4.2.2.3.1 *General*

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

4.2.2.3.2 *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 Reference 14 and is equally valid in these respects for propeller powerplants (see 4.2.1.3.3).

4.2.2.3.3 *Static tests of the gas generator*

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

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

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

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

Such circumstances where the propeller and its aerodynamic performance remain unchanged include, for example, changes to the compressor, turbine or combustor of the powerplant. The effect of such changes should be conducted under the same test, measurement, data reduction and extrapolation procedures as described in 4.2.1.3 for turbojet and turbofan engines. The noise emanating from any propeller or other power extraction device used in static tests should be eliminated or removed analytically. For the purposes of aeroplane EPNL calculation, the measured "flight datum" aeroplane propeller contributions should be included in the computation process.

4.2.3 Helicopters and tilt-rotors

The objective of a noise certification test is to acquire data for establishing an accurate and reliable definition of a helicopter's or tilt-rotor's noise characteristics (see 8.7 of Chapter 8 and 13.7 of Chapter 13 of the Annex). The Annex establishes a range of test conditions and procedures for adjusting measured data to reference conditions.

4.2.3.1 ***Flight test procedures***

4.2.3.1.1 *Helicopter and tilt-rotor test speed*

There are two requirements for aircraft test speeds. Firstly, the airspeed during the 10 dB-down period should be close to the reference speed (i.e. within ±9 km/h (±5 kt), see 8.7.6 of Chapter 8 or 13.7.6 of Chapter 13 of the Annex) in order to minimize speed adjustments for the three certification conditions of take-off, overflight and approach.

The second speed requirement applies to the overflight case (see 8.7.7 of Chapter 8 of the Annex). The number of level overflights made with a headwind component shall be equal to the number of overflights made with a tailwind component. The objective is to minimize the effect of wind on the measured overflight noise levels. If, however, the absolute wind speed component in the direction of flight, as measured at a height of 10 m (33 ft) above ground, is less than ±2.6 m/s (±5 kt), then the effect of wind direction can be considered to be negligible. In this case, the measured overflight can be considered to be either a headwind or tailwind test run.

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

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

4.2.3.1.2 *Atmospheric test conditions*

The temperature, relative humidity and wind velocity limitations are contained in 2.2.2.4 of Appendix 2 of the Annex. The parameters are measured at 10 m (33 ft) within 2 000 m (6 562 ft) of the flight track noise measurement point at a location subject to approval by the certificating authority. For adjustment purposes the measured values of these parameters are assumed to be representative of the air mass between the aircraft 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.

4.2.3.1.3 *Temperature and relative humidity measurements*

Temperature and relative humidity measurements, as defined in 2.2.2.4.2 of Appendix 2 of the Annex, have to be made at a height of 10 m (33 ft) above the ground. The measured values are used in the adjustment of the measured one-third octave band sound pressure levels for the effects of atmospheric absorption to account for the difference in the sound attenuation coefficients in the test and reference atmospheric conditions as given in 8.3.2.1 of Appendix 2 of the Annex. The distances QK and Q_rK_r in the equations of 8.3.2.1 refer to the distances between positions on the measured and reference flight paths corresponding to the PNLTM position and the noise measurement point.

As a consequence the procedure assumes that the difference between the temperature and relative humidity at 10 m (33 ft) and the PNLTM position is zero, or small, and that the atmosphere can be represented by the values measured at 10 m (33 ft) above the ground in the vicinity of the noise measurement point (i.e. within 2 000 m (6 562 ft) of the flight track noise measurement point). Data obtained from European and U.S. certification tests over a number of years and records provided by the United Kingdom meteorological office confirm that this assumption is valid over a wide range of meteorological conditions.

Noise certification measurements may be made under test conditions where significant changes in temperature and/or relative humidity with height are expected. Of particular concern are conditions when a significant drop in humidity with altitude is expected. Such special conditions might be encountered in desert areas shortly after sunrise where the temperature near the ground is lower and the relative humidity considerably higher than at the height associated with the PNLTM point. Measurements made under such conditions should be adjusted by using the average of the temperature and relative humidity measured at 10 m (33 ft) above the ground and at the height associated with the PNLTM point in order to eliminate errors associated with the use of data measured at 10 m (33 ft) only (see also 4.2.3.1.5).

Section 2.2.2.4.1 of Appendix 2 of the Annex 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 that 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.

4.2.3.1.4 *Modifications or upgrades to helicopters involving large aerodynamic drag changes*

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

a) for helicopters to be certificated under Chapter 8 of the Annex, 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, an overflight test and, if considered appropriate by the certificating authority, take-off and/or approach tests are performed by using the appropriate noise certification reference and test procedures;

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

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

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

Note.— Modifications or upgrades involving aerodynamic drag changes that do not require noise certification are described in 2.3.1.

4.2.3.1.5 *Anomalous test conditions*

Section 2.2.2.4.1 of Appendix 2 of the Annex requires that the tests be conducted under conditions where no anomalous meteorological conditions exist. The presence of anomalous atmospheric conditions can be determined to a sufficient level of certainty by monitoring the outside air temperature (OAT) with the use of the aircraft instruments. Anomalous conditions that could impact the measured levels can be expected to exist when the OAT at 150 m (492 ft) is higher by 2°C (3.6°F) or more than the temperature measured at 10 m (33 ft) above ground level. This check can be made in level flight at a height of 150 m (492 ft) within 30 minutes of each noise measurement.

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 (394 ft) and 150 m (492 ft) can be used depending on the flight condition and agreement of the certificating authority prior to the tests being conducted.

If tests are adjusted by using the "average" of the temperature and relative humidity measured at 10 m (33 ft) and the height associated with the PNLTM point (as described in the third paragraph of 4.2.3.1.3) then the provisions of the first paragraph of this section do not apply. The reason is that the impact of any anomalous meteorological conditions is 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.

4.2.3.1.6 *Helicopter and tilt-rotor test rotor speed*

Operational rotor speed modes (e.g. CAT A) can form part of the normal procedures of the aircraft flight manual and are used under specific operational circumstances. They typically involve airspeed ranges below those of the certification reference procedures. However, in some cases, such as a high pilot workload in the final approach phase, combined with instrument flight rules (IFR) conditions, their use has been permitted at higher airspeeds that include the reference speed for noise certification. Hence, the maximum normal operating rotor speed corresponding to the reference flight condition should take into account any relevant operational rotor speed mode. The decision on how and which operational rotor speed modes are to be applied for noise certification is normally coordinated with the flight test experts of the certificating authority and is dealt with on a case-by-case basis.

4.2.3.1.7 *Helicopter and tilt-rotor test mass*

The mass of the aircraft during the noise certification demonstration (see section 8.7.11 of Chapter 8 or 13.7.11 of Chapter 13 of the Annex) must lie within the range of 90 per cent to 105 per cent of the maximum take-off mass for the take-off and overflight demonstrations and between 90 per cent to 105 per cent of the maximum landing mass for the approach demonstration. For noise certification purposes the effect of change of mass is to change the test-day flight path for take-off, and adjustments to the reference flight path should be made for spherical spreading and atmospheric attenuation as described in section 8 of Appendix 2 of the Annex.

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

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

4.2.3.1.8 *Helicopter and tilt-rotor approach*

Section 8.7.10 of Chapter 8 and 13.7.10 of Chapter 13 of the Annex constrains the approach demonstration to within ±0.5 ° of the reference approach angle of 6°. Adjustments of the noise data to the reference approach angle are required to account for spherical spreading effects and atmospheric attenuation as described in section 8 of Appendix 2 of the Annex.

4.2.3.2 ***Analytical procedures***

4.2.3.2.1 *Helicopter and tilt-rotor test window for zero adjustment for atmospheric attenuation*

There is currently a “test window” contained in 2.2.2.4.1 of Appendix 2 of the Annex that needs to be met before test results are acceptable to certificating authorities. In addition if the test conditions fall within a “zero attenuation adjustment window” (see Figure 4-29), defined as the area enclosed by (2°C, 95 per cent RH), (30°C, 95 per cent RH), (30°C, 35 per cent RH), (15°C, 50 per cent RH) and (2°C, 90 per cent RH), then the sound attenuation adjustment of the test data may be assumed to be zero.

Accordingly the terms:

$$0.01\,[\alpha(i) - \alpha_{\mathrm{R}}(i)]\mathrm{QK}, \text{ and}$$

$$0.01\alpha_{\mathrm{R}}(i)\,(\mathrm{QK} - \mathrm{Q}_r\mathrm{K}_r),$$

from the equation for $\mathrm{SPL}(i)_r$ in 8.3.2.1 of Appendix 2 of the Annex become zero and the equation for $\mathrm{SPL}(i)_r$ becomes:

$$\mathrm{SPL}(i)_r = \mathrm{SPL}(i) + 20\log(\mathrm{QK}/\mathrm{Q}_r\mathrm{K}_r).$$

Furthermore, in this equation QK and $\mathrm{Q}_r\mathrm{K}_r$ may be replaced by the test and reference distances to the aircraft when the aircraft is over the centre noise measuring point provided that all the measured points for a particular flight condition are:

a) flown in test conditions within the "zero attenuation adjustment window" defined in Figure 4-29;

b) for overflight, the height is 150 ± 9 m (492 ± 30 ft);

c) for approach, the height over the microphone is 120 ± 10 m (394 ± 33 ft); and

d) for take-off, the distance adjustment given in 8.7.4 a) of Chapter 8 and 13.7.4 a) of Chapter 13 of the Annex is not greater than 2 EPNdB.

The total effect of both simplifications cited above is that the equation in 8.3.2.1 of Appendix 2 of the Annex becomes:

$$\mathrm{SPL}(i)_r = \mathrm{SPL}(i) + 20\log(\mathrm{HK}/\mathrm{H_rK_r}),$$

and the duration adjustment term specified in 8.3.4 of Appendix 2 of the Annex becomes:

$$\Delta_2 = -7.5\log(\mathrm{HK}/\mathrm{H_rK_r}) + 10\log(\mathrm{V}/\mathrm{V_R}),$$

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

4.2.3.2.2 *Procedure for the determination of source noise adjustment*

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

In order to eliminate the need for a separate source noise adjustment to the overflight test results, the following test procedure is considered acceptable when the correlating parameter is the main rotor advancing blade tip Mach number, M_{AT}.

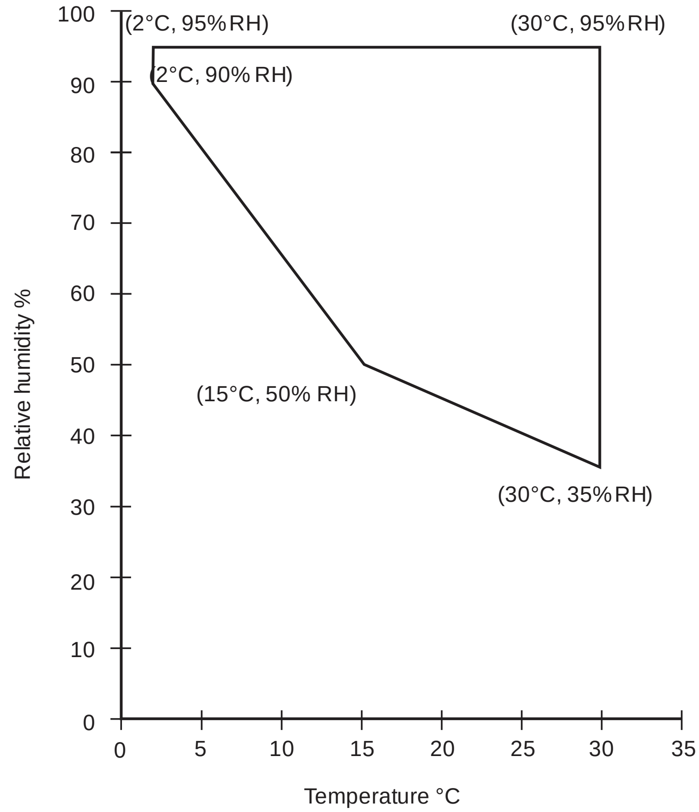


Figure 4-29. Chapter 8 zero attenuation adjustment window

Each overflight noise test must be conducted such that:

a) the adjusted reference true airspeed, V_{AR}, is the reference airspeed, V_R, specified in 8.6.3.1 of Chapter 8 and 13.6.3.1 of Chapter 13 of the Annex adjusted as necessary to produce the same main rotor advancing blade tip Mach number as associated with reference conditions;

Note 1.— For helicopters the reference advancing blade tip Mach number, M_{ATR}, is defined as the ratio of the arithmetic sum of the reference main rotor blade tip rotational speed, V_{tipR}, and the helicopter reference speed, V_R, divided by the speed of sound, c_R, at 25°C (346.1 m/s) such that:

$$M_{ATR} = \frac{V_{tipR} + V_R}{c_R}$$

and the adjusted reference true airspeed, V_{AR}, is calculated from:

$$V_{AR} = c\left(\frac{V_{tipR} + V_R}{c_R}\right) - V_{tipR}$$

where c is the speed of sound calculated from the on-board measurement of outside air temperature (see 3.8).

Note 2.— For tilt-rotors, the reference advancing blade tip Mach number (M_R) is defined as the ratio of the vector sum of the reference rotor blade tip rotational speed (V_{tipR}) *and the tilt-rotor reference speed* (V_R) *divided by the speed of sound* (c_R) *at 25°C (346.1 m/s) such that:*

$$M_R = \frac{\left[V_{tipR}{}^2 + V_R{}^2 - 2 \times V_{tipR} \times V_R \times \cos\left(I_N + 90^\circ\right)\right]^{1/2}}{c_R}$$

where I_N is the nacelle incidence angle in degrees for the overflight condition. The adjusted reference airspeed (V_{AR}) *is calculated from:*

$$V_{AR} = V_{tipR} \times \cos\left(I_N + 90^\circ\right) + \left(V_{tipR}^2 \times \cos\left(I_N + 90^\circ\right)^2 + \left(\frac{c}{c_R}\right)^2 \left(V_{tipR}^2 + V_R^2 - 2 \times V_{tipR} \times V_R \times \cos\left(I_N + 90^\circ\right)\right) - V_{tipR}^2\right)^{1/2}$$

where c *is the speed of sound calculated from the on-board measurement of outside air temperature.*

b) the test true airspeed shall not vary from the adjusted reference true airspeed, V_{AR}), by more than ±5.5 km/h (±3 kt) or an equivalent approved variation from the reference main rotor advancing blade tip Mach number, M_{ATR};

c) in practice, the tests will be flown to an IAS that is the adjusted reference true airspeed, V_{AR}, with corrections for compressibility effects and instrument position errors removed; and

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

Note.— The calculation of noise levels, including the adjustments, is the same as that described in Chapter 8, Chapter 13 and Appendix 2 of the Annex except that the need for source noise adjustment is eliminated. It should be emphasized that in the determination *of the duration adjustment (Δ_2), the speed component of the duration adjustment is calculated as 10 log (V_G / V_{GR}) where V_G is the test ground speed and V_{GR} is the reference ground speed.*

4.3 TECHNICAL PROCEDURES INFORMATION

4.3.1 Jet and propeller-driven aeroplanes, helicopters and tilt-rotors

4.3.1.1 ***Adjustment of measured noise data to reference conditions***

Section 8.2 of Appendix 2 of the Annex provides for the use of either simplified or integrated methods for adjusting measured noise data to reference conditions. Criteria for selecting the adjustment method are given. Guidance in the form of technical procedures for performing each of these two adjustment methods is provided in the following sections.

4.3.1.2 ***Determination of reference-condition noise geometry***

For either the simplified or integrated adjustment method, aircraft noise geometry must be determined in order to locate the aircraft position on the reference flight path.

The method described in this section illustrates the fundamental principles and key elements of aircraft noise geometry. It is not recommended as the only acceptable method. Other methods may be preferable depending on the techniques used for acquisition and adjustment of test data. Acceptable methods will have within them key elements consistent with these principles. Note that all methods, including the method described in this section, and the manner in which they are implemented by the applicant, are subject to approval by the certificating authority.

The methodology presented is dependent on obtaining an average, straight-line flight path that represents the test aircraft position during noise measurements. This method is based on characterizing this average straight-line flight path by a set of single-point descriptors, which can be easily obtained from any method of aircraft TSPI measurement data. Geometry relative to each centre line (flyover and approach) and lateral microphone of interest is then determined for the test data, including sound emission coordinates (t, X, Y, Z) for each measured acoustic spectrum (*k*) in the acoustic spectral time-history data set. Once the sound emission coordinates have been identified, sound propagation distances and sound emission angles are calculated, which are used to determine the position of the aircraft on the reference flight path. For the integrated method of adjustment only, the series of positions on the reference flight path are then used to obtain the effective duration for each spectrum *k* for the reference condition acoustic data set.

4.3.1.2.1 *Assumptions*

a) The test aircraft position during noise measurements can be represented by a straight line flight path;

b) The ground reference system used in the figures, a right-handed coordinate system, is assumed to be fixed to the surface of a flat earth with the x-axis pointing along the reference ground track, the y-axis pointing to the left of the reference ground track, and the z-axis pointing up;

Note.— For aeroplanes the term "reference ground track" refers to the "extended centre line of the runway" or the "extended runway centre line" referred to in 3.3.1 and 5.3.1 of the Annex.

c) The point on the ground directly beneath the centre line microphone is the origin of the XYZ coordinate system (X = 0, Y = 0, Z = 0);

d) The X-coordinate value increases with time as the aircraft moves through the noise measurement test site;

e) The single-point flight path descriptors represent average values over the noise duration as defined in section 4.5 of Appendix 2 of the Annex; and

f) Angular quantities are expressed in radians except where otherwise noted.

4.3.1.2.2 *Steps involved*

a) Characterization of a straight-line average test flight path based on descriptors for a single point (see 4.3.1.2.3);

b) Determination of test aircraft position at time of sound emission of each acoustic spectrum (see 4.3.1.2.4);

c) Calculation of the geometric minimum distance between the test flight path and the microphone (see 4.3.1.2.5);

d) Determination of test aircraft noise geometry (sound propagation distance and sound emission angle) for each acoustic spectrum (see 4.3.1.2.6);

e) Determination of reference flight path (see 4.3.1.2.7);

f) Determination of reference sound propagation distance for each acoustic spectrum (see 4.3.1.2.8); and

g) Determination of effective duration for each acoustic spectrum for the integrated procedure (see 4.3.1.2.9).

4.3.1.2.3 *Characterization of a straight-line average flight path based on descriptors for a single point*

A straight-line flight path can be defined knowing the aircraft position, speed and three-dimensional direction (vector) at a single point in time (see Figure 4-30). For the method described in this section the "single-point" descriptors are:

t_{OH} is the time at overhead (the time when the aircraft X coordinate = 0.0);

X_{OH} is the X coordinate of the centre line microphone, X = 0.0;

Y_{OH} is the lateral offset of the aircraft from the reference ground track at t_{OH};

Z_{OH} is the aircraft height above the reference X-Y ground plane at t_{OH};

V_G is the average groundspeed over the noise duration;

γ is the average climb/descent angle; and

χ is the average lateral cross-track angle.

Note.— The average ground speed, V_G, used in calculations for aircraft noise geometry is independent from any cockpit instrumentation and is to be determined from the aircraft position measurements. For reference conditions, the reference groundspeed, V_{GR}, is to be determined from the reference climb/descent angle and its relationship to the reference true airspeed value, V_R.

Generate the straight-line average aircraft flight path t, X, Y, Z position time history from the single-point flight path descriptors at an appropriate sample rate (typically two times per second):

For any relative time, t(p):

$$X(p) = (t(p) - t_{OH})\,(V_G \cos(\chi)) + X_{OH};$$

$$Y(p) = (t(p) - t_{OH})\,(V_G \sin(\chi)) + Y_{OH}; \text{ and}$$

$$Z(p) = (t(p) - t_{OH})\,(V_G \tan(\gamma)) + Z_{OH}$$

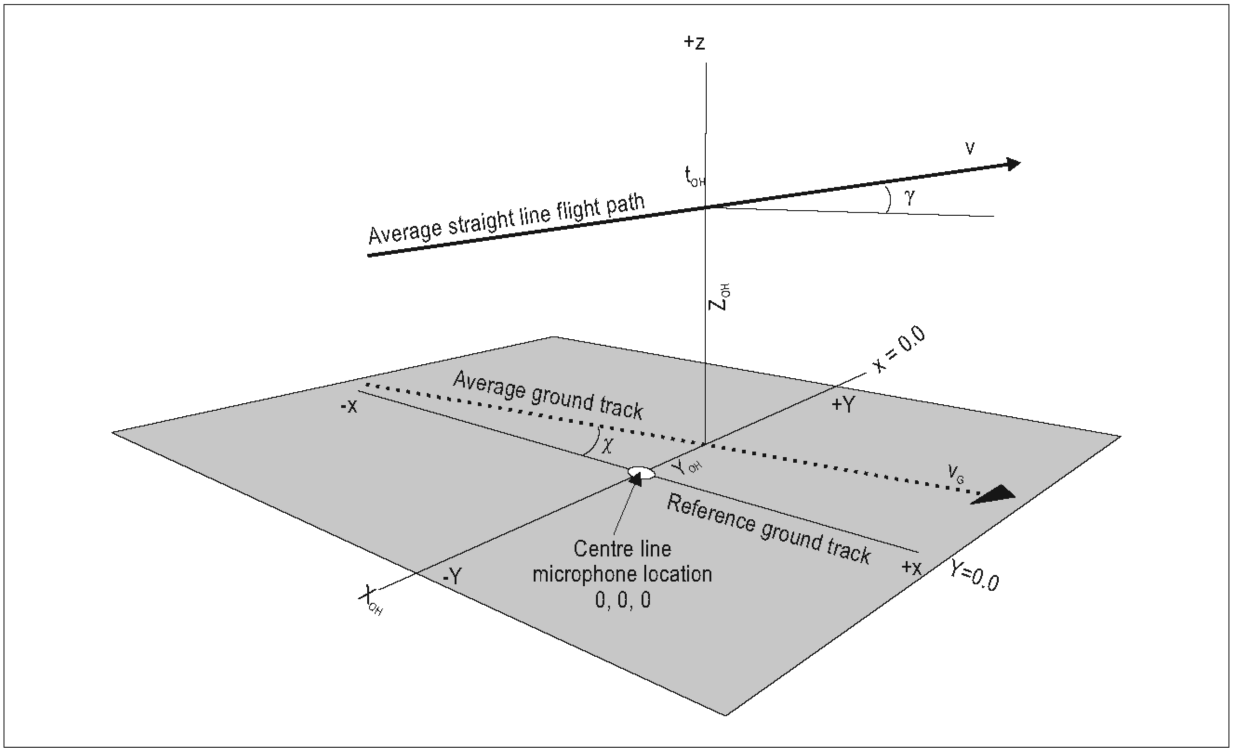


Figure 4-30. Single-point flight path descriptors

4.3.1.2.4 *Determination of test aircraft position at time of sound emission of each acoustic spectrum*

Sound emitted from the aircraft takes a finite time to propagate prior to being received at the measurement microphone. During this time, the aircraft has travelled a finite distance along the flight path. Therefore, it is necessary to determine the time and position coordinates of the aircraft for the point of sound emission for each acoustic record *k* (see Figure 4-31).

The spectral time history of measured aircraft noise data includes a series of slow sample times as specified in section 3.7.6 of Appendix 2 of the Annex. For each of these measurement times, $t_m(k)$, the associated time of sound emission, $t_E(k)$, as well as the sound emission coordinates, $X_E(k)$, $Y_E(k)$, $Z_E(k)$, can be determined using information about the microphone, the measured aircraft position and time, and the test speed of sound (c).

The microphone position descriptors are:

X_{MIC} is the longitudinal distance along the reference ground track, between microphone location and coordinate system origin (typically 0.0);

Y_{MIC} is the lateral distance between microphone location and the reference ground track (typically 0.0 for centre line microphone, and ±150 metres or ±450 metres for lateral microphones);

Z_{MIC} is the height of ground at microphone location relative to the reference ground plane (typically 0.0); and

H_{MIC} is the height of microphone above local ground (1.2 metres);

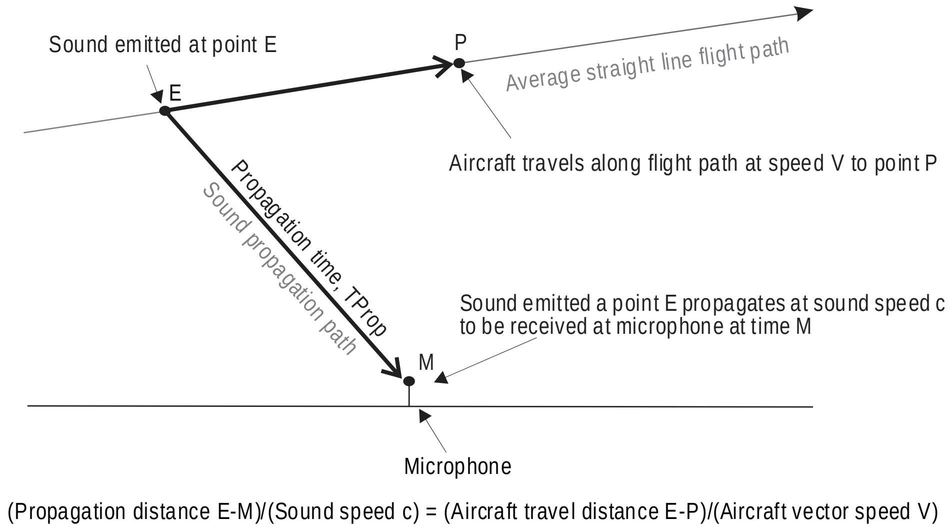


Figure 4-31. Aircraft position at time of sound emission

Using the average straight-line flight path position time history from 4.3.1.2.3 and the microphone position descriptors listed above, develop an emission/reception array for eventual determination of aircraft sound emission coordinates for each measured acoustic spectral data record, *k*, as follows:

Calculate sound speed, c, for test-day conditions (see 3.8);

For each *p*-th aircraft position sample in the position time history, t(*p*), X(*p*), Y(*p*) and Z(*p*), calculate the following:

Slant range between the aircraft and the microphone:

$$SR(p) = \{(X(p) - X_{MIC})^2 + (Y(p) - Y_{MIC})^2 + [Z(p) - (Z_{MIC} + H_{MIC})]^2\}^{0.5}$$

Sound propagation time:

$$t_{prop}(p) = SR(p) / c$$

Reception time:

$$t_{rec}(p) = t(p) + \delta t_{prop}(p)$$

The emission/reception array should now include the following for each aircraft position:

$$t(p),\ X(p),\ Y(p),\ Z(p) \text{ and } t_{rec}(p)$$

Using linear interpolation, determine the time of sound emission, $t_E(k)$, for each k-th measured acoustic spectral data record in the spectral time history:

$$t_E(k) = t(p_2) + [(t(p_1) - t(p_2)) \times (t_m(k) - t_{rec}(p_2)) / (t_{rec}(p_1) - t_{rec}(p_2))]$$

where:

- $t_E(k)$ is the relative time when spectrum k was emitted;
- $t_m(k)$ is the acoustic measurement time for spectral record k (as per section 3.7.6 of Appendix 2 of the Annex)
- p_1 is the aircraft position record where $t_{rec}(p)$ is > $t_m(k)$; and
- p_2 is the aircraft position record where $t_{rec}(p)$ is < $t_m(k)$.

Once the time of sound emission has been determined generate the sound emission coordinates $X_E(k)$, $Y_E(k)$ and $Z_E(k)$ for each k-th measured acoustic spectral data record as follows:

$$X_E(k) = (t_E(k) - t_{OH})\ (V_G \cos(\chi)) + X_{OH};$$

$$Y_E(k) = (t_E(k) - t_{OH})\ (V_G \sin(\chi)) + Y_{OH}; \text{ and}$$

$$Z_E(k) = (t_E(k) - t_{OH})\ (V_G \tan(\gamma)) + Z_{OH}$$

4.3.1.2.5 *Calculation of the geometric minimum distance between the test flight path and the microphone*

Using the single-point flight path descriptors identified in 4.3.1.2.3 and the coordinates of the microphone identified in 4.3.1.2.4, calculate the geometrical minimum distance (closest point of approach or "CPA"), the line from the microphone of interest that intersects the straight line flight path at right angles:

$$CPA = (Gnorm^2 + GCPA^2)^{0.5}$$

Intermediate calculations for determination of CPA (see Figures 4-32 and 4-33) include:

$$Ydis = Y_{MIC} - Y_{OH}$$
Lateral distance from microphone to average ground track at t_{OH}

$$Gnorm = (Ydis) \cos(\chi)$$
Line on the ground from the microphone location that intersects the average ground track at right angles

$$Malt = Z_{OH} - (Z_{MIC} + H_{MIC})$$
Vertical distance of flight path above microphone

$$Ginc = (Ydis) \sin(\chi)$$
Distance along average ground track between X = 0.0 and intersection with Gnorm

$$Zinc = (Ginc) \tan(\gamma)$$
Vertical difference between Galt and Z_{OH}

$$Galt = Malt + Zinc$$
Vertical height of flight path above microphone at intersection of Gnorm and average ground track

$$GCPA = (Galt) \cos(\gamma)$$

Line from the point at the microphone height (H_{MIC}) vertically above the point where Gnorm intersects the average ground track, which intersects the average straight line flight path at right angles

Note.— In contrast to Figure 4-31, the horizontal X-Y plane illustrated in Figure 4-32 is now at the height of the microphone, not the reference ground plane where Z = 0.0.

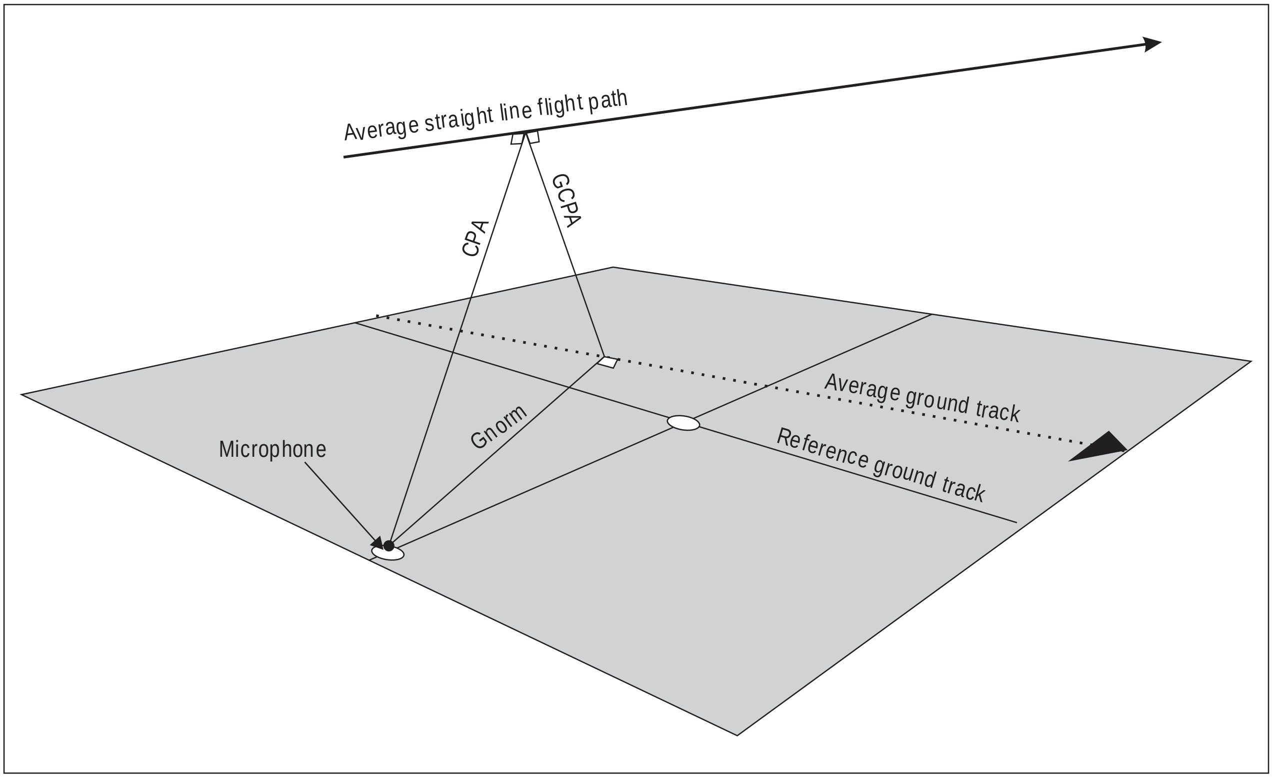


Figure 4-32. Basic CPA geometry

Note.— Figure 4-33 illustrates the CPA geometry for a lateral microphone, but also includes intermediate elements used in the calculation of Gnorm and GCPA applicable to a centre line microphone. Also, the X-Y plane in this figure is at the height of the lateral microphone.

4.3.1.2.6 *Determination of test aircraft noise geometry (sound propagation distance and sound emission angle) for each acoustic spectrum*

Using the sound emission coordinates from 4.3.1.2.4 calculate slant range SR(*k*), the sound propagation distance between the aircraft and the microphone, for each spectrum k in the spectral time history (see Figure 4-34):

$$SR(k) = [(X_E(k) - X_{MIC})^2 + (Y_E(k) - Y_{MIC})^2 + (Z_E(k) - [Z_{MIC} + H_{MIC}])^2]^{0.5}$$

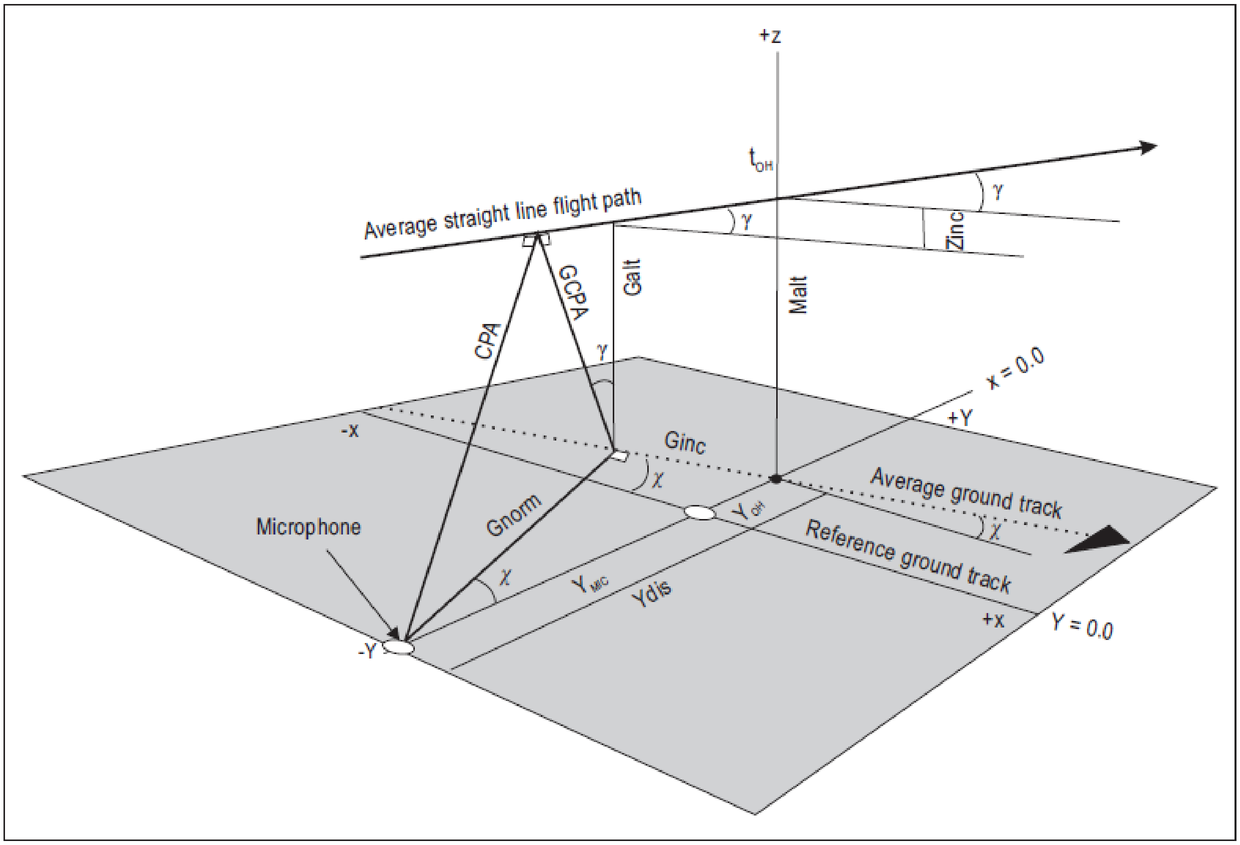


Figure 4-33. Detailed CPA geometry

Using the sound propagation distance, SR(k), and the geometric minimum distance between the flight path and microphone, CPA, from 4.3.1.2.5, calculate the three-dimensional sound emission angle, θ, for each spectrum k (see Figure 4-35):

$\theta(k) = \arcsin(CPA / SR(k))$ when aircraft is positioned prior to CPA;

$\theta(k) = \pi/2$ (i.e. 90 degrees) when aircraft is positioned at CPA; and

$\theta(k) = \pi - \arcsin(CPA / SR(k))$ when aircraft is positioned subsequent to CPA.

The resulting noise geometry time history for each acoustic spectral data record k now includes:

$t_m(k)$ is the acoustic measurement time for spectrum k;

$t_E(k)$ is the sound emission time for spectrum k, received at the microphone at $t_m(k)$;

$X_E(k)$ is the X-coordinate at time of sound emission for spectrum k;

$Y_E(k)$ is the Y-coordinate at time of sound emission for spectrum k;

$Z_E(k)$ is the Z-coordinate at time of sound emission for spectrum k;

SR(k) is the sound propagation distance (slant range) for spectrum k; and

θ(k) is the three-dimensional sound emission angle for spectrum k.

Note.— SR(k) is used for calculations of sound attenuation due to spherical spreading, as well as for sound attenuation due to atmospheric absorption, and for the distance-dependent portion of the Δ_2 duration adjustment term used in the simplified method; θ(k) is used for determining the aircraft position on the reference flight path when adjusting noise data to reference conditions.

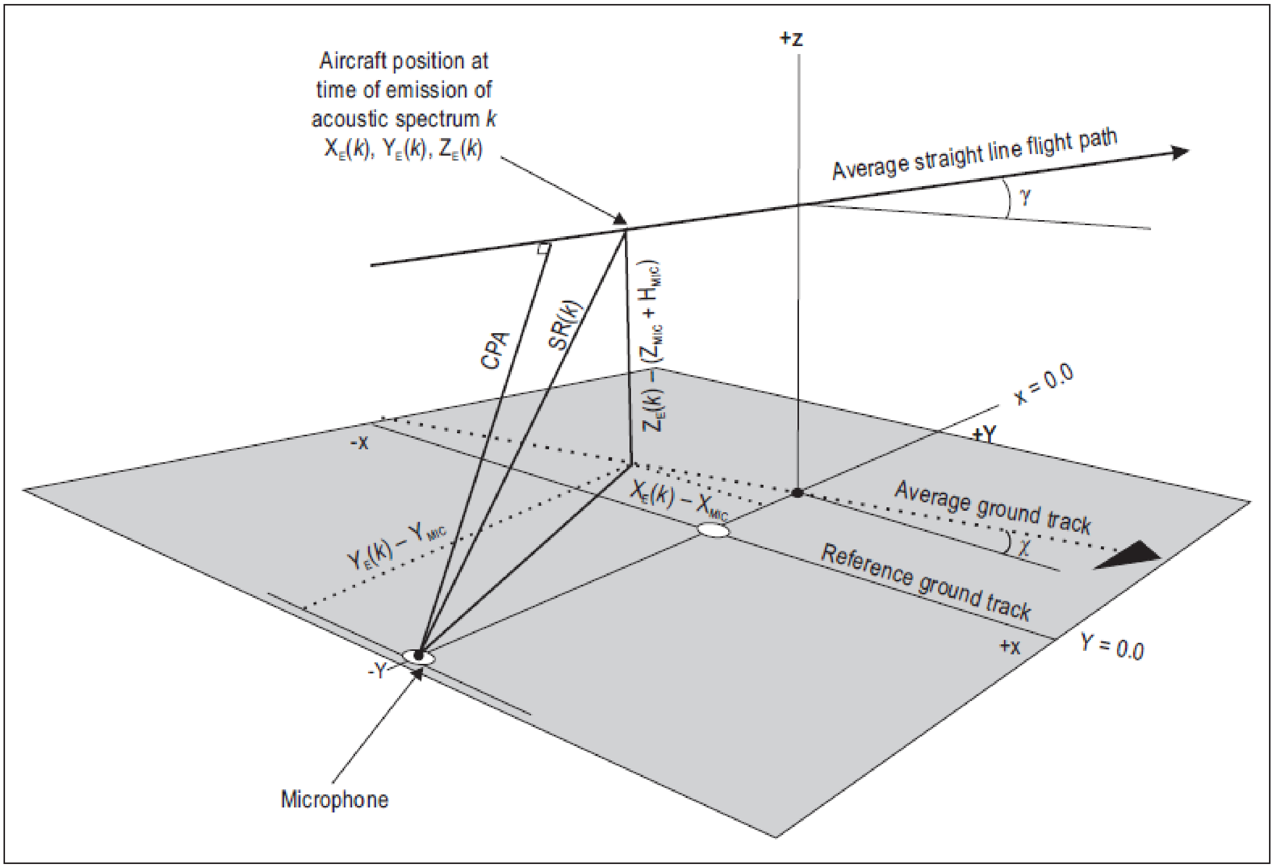


Figure 4-34. Sound propagation distance, SR(k)

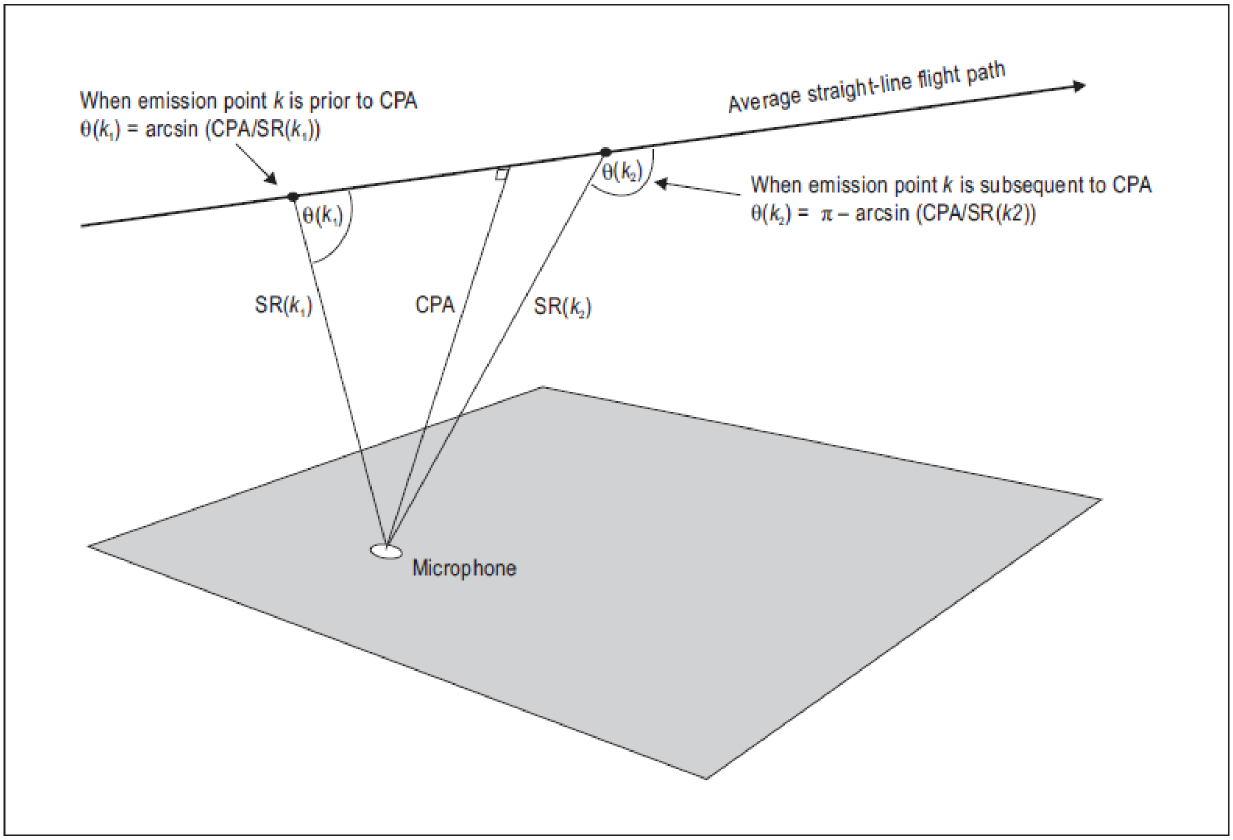


Figure 4-35. Sound emission angle, θ

4.3.1.2.7 *Determination of reference flight path*

By definition, the reference flight path is a straight line with no lateral displacement. This makes the associated noise geometry relatively simple.

The reference flight path geometry has the following characteristics:

Z_{OHR} is the vertical height of the reference flight path above the reference ground plane at t_{OH};

V_{GR} is the reference groundspeed;

c_R is the reference sound speed, 346.1 m/s (1 135.5 ft/s) as per 3.8;

γ_R is the reference climb/descent angle;

Y_{MICR} is the lateral distance between the reference microphone location and the reference ground track; and

H_{MICR} is the height of the reference microphone (1.2 metres) above the reference ground plane.

Calculate CPA_R, the reference flight path geometrical minimum distance, or closest point of approach to microphone (see Figure 4-36 a) and b)):

$$CPA_R = (CPA_{OHR}^2 + Y_{MICR}^2)^{0.5} \text{ where:}$$

$$CPA_{OHR} = (Z_{OHR} - H_{MICR}) \cos(\gamma_R)$$

Note.— CPA_{OHR} is the minimum distance directly under the reference flight path between the reference flight path and the reference microphone height at the intersection of the reference ground track and the lateral microphone line. For centre line microphones, $CPA_R = CPA_{OHR}$.

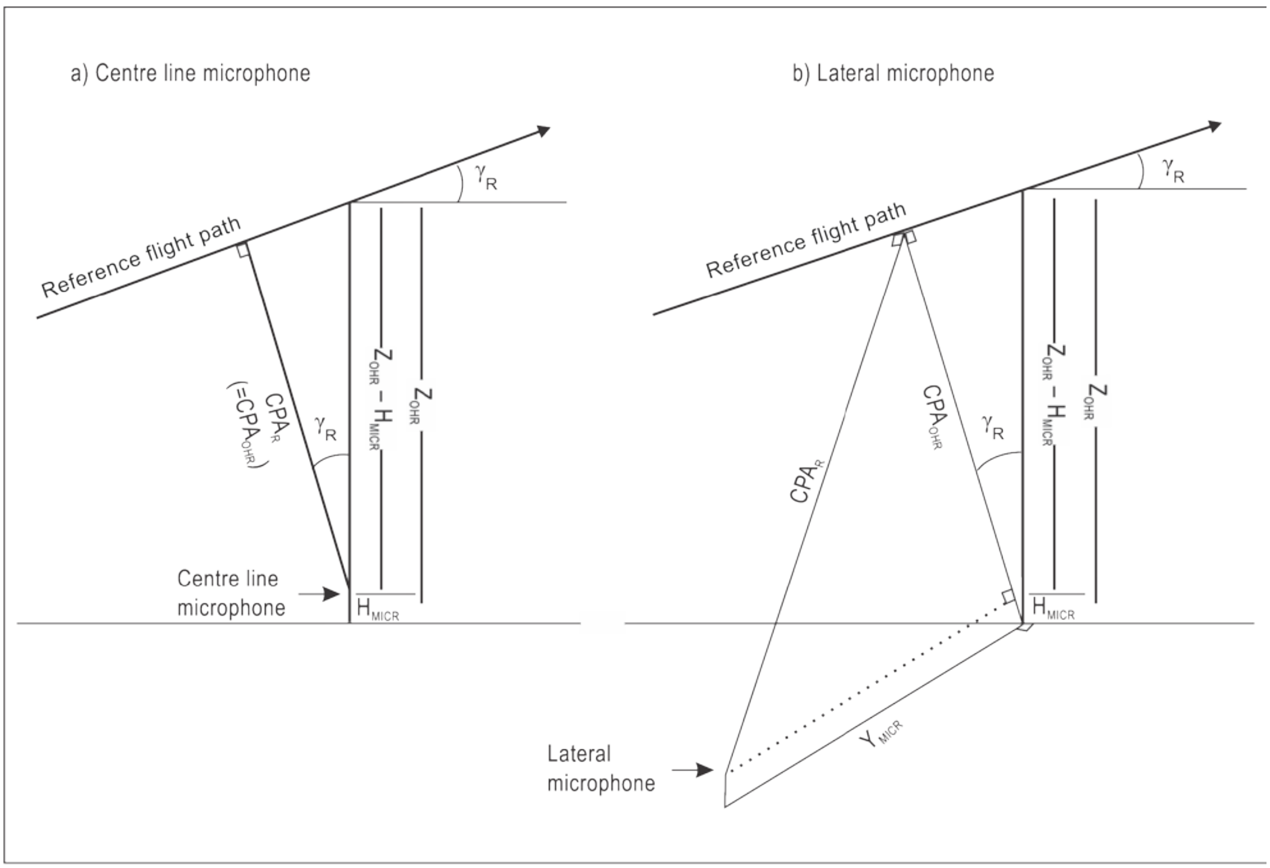


Figure 4-36. CPA_R for centre line and lateral microphones

4.3.1.2.8 *Determination of reference sound propagation distance for each acoustic spectrum*

The reference sound propagation distance, $SR_R(k)$, can be determined from the geometric relationship between the sound emission angle, $\theta(k)$, which is kept constant between the test and reference cases, and the geometric minimum distance between the reference microphone and the reference flight path, CPA_R (see Figure 4-37):

$$SR_R(k) = CPA_R / \sin(\theta(k))$$

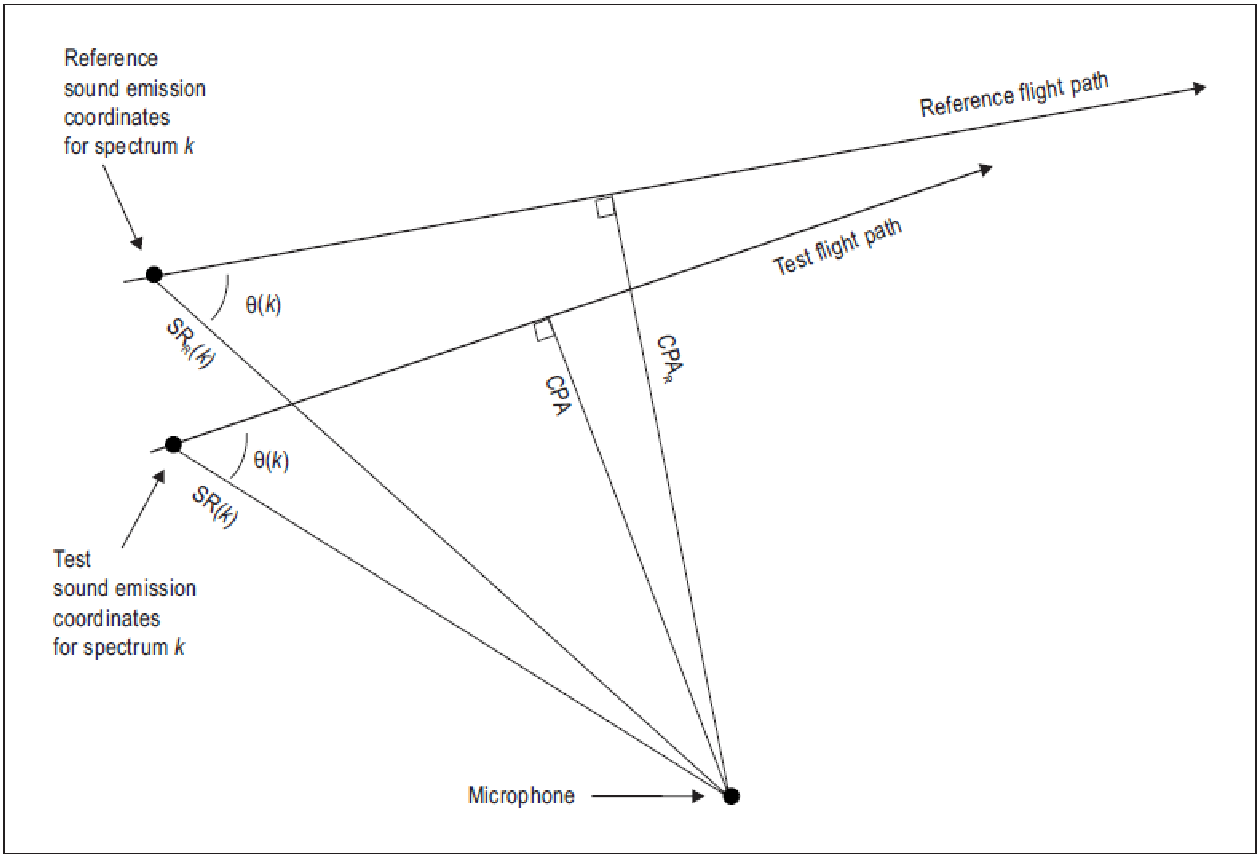


Figure 4-37. Determination of reference sound propagation distance, SR_R(k)

4.3.1.2.9 *Determination of effective duration for each acoustic spectrum for the integrated procedure*

When using the integrated method of adjustment described in section 8.4 of Appendix 2 of the Annex, an effective duration ($\delta t_R(k)$) for each reference condition PNLT value must be determined for use in the calculation of EPNL. The uniform, one-half second time intervals between the samples of the measured test aircraft noise data become non-uniform when projected to the reference case, due to adjustments for differences between test and reference conditions. The effective duration represents the time interval between successive acoustic data samples that would have been measured at the reference microphone under reference conditions.

Two elements are involved in determining the "measurement" time for each reference condition acoustic data sample, *k*:

a) the time of sound emission, $t_{ER}(k)$; and

b) the sound propagation time, $\delta t_{propR}(k)$.

Determining the time of sound emission, $t_{ER}(k)$, for reference conditions requires calculation of three distances along the reference flight path, $FPDist(CPA_R)$, $FPInc_R(k)$, and $FPDist_R(k)$ (see Figure 4-38).

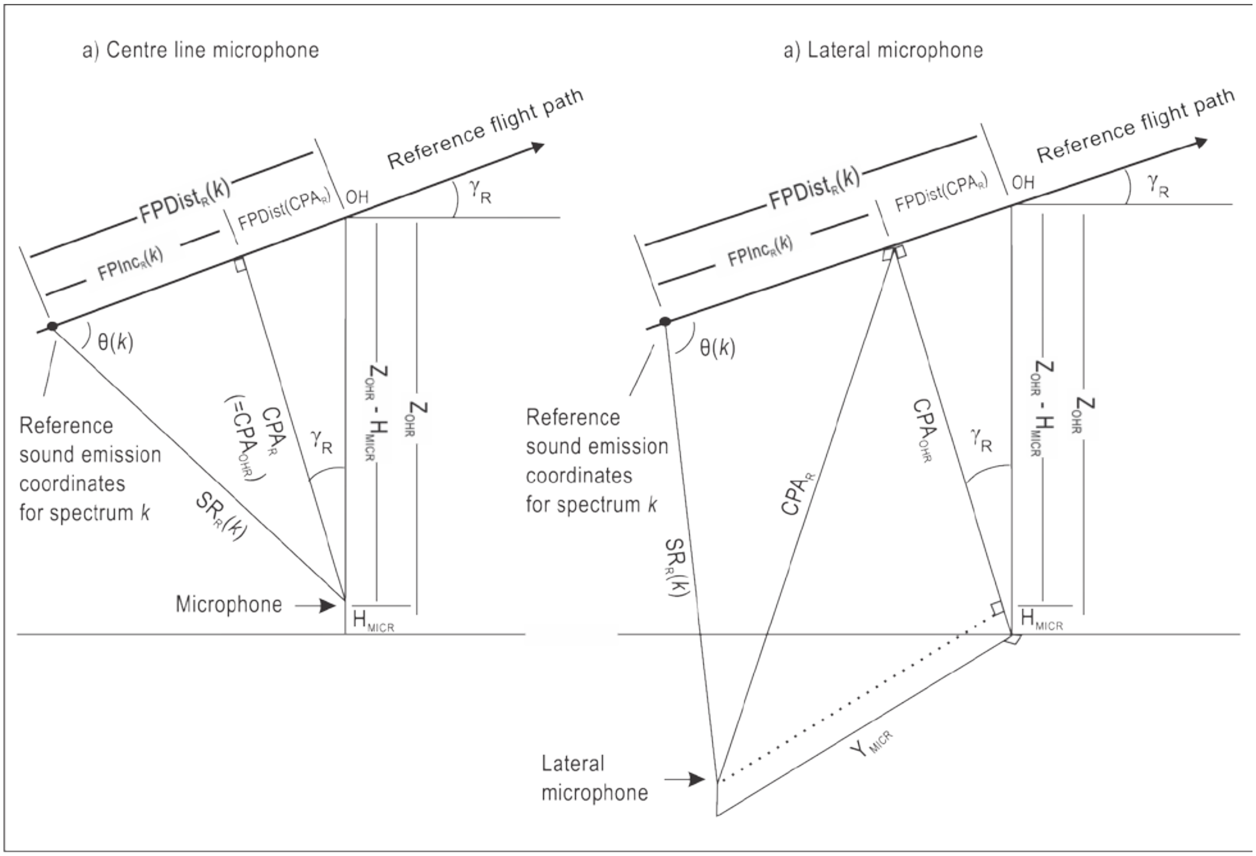


Figure 4-38. FPDist concept for centre line and lateral microphones

FPDist(CPA_R) is the distance along the reference flight path from CPA_R to t_{OH} (taking its sign from the reference climb/descent angle, γ_R), such that:

$$\text{FPDist}(CPA_R) = (CPA_{OHR}) \tan(\gamma_R)$$

Note.— FPDist(CPA_R) is positive when γ_R is positive.

$\text{FPInc}_R(k)$ is the distance along the reference flight path from sound emission point k to CPA_R, such that:

$\text{FPInc}_R(k) = CPA_R / \tan(\theta(k))$, taking its sign from sound emission angle $\theta(k)$ as follows:

$\text{FPInc}_R(k)$ is positive when $\theta(k) < \pi/2$ (i.e. < 90 degrees);

$\text{FPInc}_R(k) = 0$ when $\theta(k) = \pi/2$ (i.e. 90 degrees); and

$\text{FPInc}_R(k)$ is negative when $\theta(k) > \pi/2$ (i.e. > 90 degrees).

$\text{FPDist}_R(k)$ is the distance along the flight path from point k to the overhead point, such that:

$$\text{FPDist}_R(k) = \text{FPDist}(CPA_R) + \text{FPInc}_R(k)$$

Note.— $FPDist_R(k)$ is positive when k is before overhead.

$t_{ER}(k)$ is the time of sound emission for point k (found in this case by backing the aircraft along the flight path from t_{OH}), such that:

$$t_{ER}(k) = t_{OH} – (FPDist_R(k) / V_R)$$

Note.— V_R is the true airspeed for reference conditions.

$\delta t_{propR}(k)$ is the sound propagation time for sound emission point k, such that:

$$\delta t_{propR}(k) = SR_R(k) / c_R$$

$t_R(k)$ is the time of sound reception at the microphone for sound emitted at point k, such that:

$$t_R(k) = t_{ER}(k) + \delta t_{propR}(k)$$

Finally calculate $\delta t_R(k)$, the effective time duration for the sound received at the microphone at time $t_R(k)$, as specified in section 8.4.3.3 of Appendix 2 of the Annex where:

$$\delta t_R(k) = [(t_R(k) – t_R(k – 1)) + (t_R(k + 1) – t_R(k))]/2$$

4.3.1.3 ***Computation of EPNL by the simplified method of adjustment***

Section 8.3 of Appendix 2 of the Annex provides specifications for the simplified adjustment method. The following procedure illustrates one method for meeting the requirements of section 8.3.

4.3.1.3.1 *Inputs required for performing the simplified method*

The following inputs are required for the simplified method:

a) The one-third octave band spectrum representing the measured test-day aircraft noise at the time of PNLTM, $SPL(i, k_M)$, plus the spectra representing the measured test-day aircraft noise for any $PNLT(k)$ values within 2 dB of the level of PNLTM (secondary peaks), $SPL(i,k)$, determined in accordance with section 4 of Appendix 2 of the Annex. Additional guidance is provided in 4.1.3 of Appendix 2 of the Annex;

b) The average atmospheric absorption coefficients, $\alpha(i)$ for each one-third octave band, i, determined for test-day conditions, in dB per 100 metres, as determined from measured test-day meteorological data in accordance with section 7 of Appendix 2 of the Annex. Additional guidance is provided in 4.1.1, under AMC A2 2.2.2.4.1 d) (Calculation of sound attenuation coefficients for the effects of atmospheric absorption);

c) The atmospheric absorption coefficients, $\alpha_R(i)$ for each one-third octave band, i, determined for reference conditions in dB per 100 metres, as determined in accordance with section 7 of Appendix 2 of the Annex. Note that reference conditions for atmospheric absorption are specified in section 3.6 of Chapter 3 of the Annex for aeroplanes being certified under Chapter 3 or Chapter 4 requirements, section 8.6 of Chapter 8 of the Annex for helicopters, and section 13.6 of Chapter 13 of the Annex for tilt-rotors, as a homogenous atmosphere with temperature of 25°C, and relative humidity of 70 per cent;

d) The sound propagation distance (in metres) between the aircraft and the microphone at the time of emission of the PNLTM noise data record, $SR(k_M)$, and for each secondary peak record, $SR(k)$, as determined in 4.3.1.2;

e) The reference sound propagation distance (in metres) between the aircraft and the reference microphone at the time of emission of the $PNLTM_R$ noise data record, $SR_R(k_M)$, and of each secondary peak record, $SR_R(k)$, as determined in 4.3.1.2;

f) The test-day bandsharing adjustment, Δ_B, as determined in section 4.4.2 of Appendix 2 of the Annex;

g) The test-day aircraft groundspeed, V_G, as determined from the measured aircraft tracking TSPI data from 4.3.1.2;

h) The reference aircraft groundspeed, V_{GR}, as determined from 4.3.1.2;

i) The test-day value for EPNL, as specified in section 4 of Appendix 2 of the Annex;

j) The test-day value for PNLTM, as specified in section 4 of Appendix 2 of the Annex; and

k) A source noise adjustment, Δ_3, as determined in section 8.3.5 of Appendix 2 of the Annex.

4.3.1.3.2 *Adjustment of sound pressure levels to reference conditions*

Adjust each measured test-day one-third octave band SPL in the spectrum associated with PNLTM, and in the spectra associated with any secondary peaks, for spherical spreading (also known as "inverse square law") and the effect of the change in sound attenuation due to atmospheric absorption for differences between the test and reference flight paths, using the equation provided in section 8.3.2.1 of Appendix 2 of the Annex:

For the measured test-day acoustic data spectrum associated with PNLTM, k_M:

For all one-third octave bands, i:

$$\begin{aligned} SPL_R(i,k_M) = {} & SPL(i,k_M) + 0.01\,[\alpha(i) - \alpha_R(i_0]\,SR(k_M) \\ & + 0.01\,\alpha_R(i)\,(SR(k_M) - SR_R(k_M)) \\ & + 20\log\,(SR(k_M)\,/\,SR_R(k_M)) \end{aligned}$$

For each measured test-day acoustic data spectrum associated with a secondary peak, k:

For all one-third octave bands, i:

$$SPL_R(i,k) = SPL(i,k) + 0.01\,[\alpha(i) - \alpha_R(i)]\,SR(k) + 0.01\,\alpha_R(i)\,(SR(k) - SR_R(k)) + 20\log\,(SR(k)\,/\,SR_R(k))$$

4.3.1.3.3 *Determination of reference-condition tone-corrected perceived noise levels*

Calculate the reference-condition tone-corrected perceived noise level, $PNLT_R(k_M)$ for the adjusted spectrum associated with PNLTM, k_M, and for each spectrum associated with a secondary peak, k, using the procedures specified in section 4 of Appendix 2 of the Annex, including calculation of perceived noise level, $PNL_R(k)$ and tone-correction factor, $C_R(k)$.

4.3.1.3.4 *Application of test-day bandsharing adjustment to reference-condition maximum tone-corrected perceived noise level and determination of the Δ_1 simplified adjustment term*

In order to account for the presence of bandsharing in the measured test-day PNLTM and EPNL, the test-day bandsharing adjustment, Δ_B, as determined in section 4.4.2 of Appendix 2 of the Annex, is applied to the adjusted reference-condition $PNLT_R(k_M)$ value prior to determination of other adjustment factors, and subsequent calculation of the simplified reference-condition effective perceived noise level, $EPNL_R$ as specified in section 8.3.2.1 of Appendix 2 of the Annex:

$$PNLTM_R = PNLT_R(k_M) + \Delta_B$$

The simplified adjustment term Δ_1 is then calculated per section 8.3.2.1 of Appendix 2 of the Annex, by subtracting the test-day (bandsharing-adjusted) value for PNLTM (as determined in accordance with section 4.4 of Appendix 2 of the Annex) from the reference-condition (bandsharing-adjusted) value for $PNLTM_R$ obtained from the equation above:

$$\Delta_1 = PNLTM_R – PNLTM$$

4.3.1.3.5 *Determination of the Δ_{Peak} simplified adjustment term to account for the effects of secondary peaks*

Using the bandsharing-adjusted reference-condition $PNLTM_R$ value as determined in 4.3.1.3.4, and the reference-condition values of $PNLT_R$ for each of the secondary peaks, as determined in 4.3.1.3.3, calculate the secondary peak adjustment term, Δ_{peak}, specified in section 8.3.3 of Appendix 2 of the Annex as follows:

a) Compare the $PNLT_R$ values for all of the secondary peaks to determine which has the maximum value of $PNLT_R$, and identify this secondary peak value as $PNLT_R(k_{M2})$;

b) If the value of $PNLT_R(k_{M2})$ exceeds that of $PNLTM_R$, then calculate the secondary peak adjustment term, Δ_{peak}, by subtracting $PNLTM_R$ from $PNLT_R(k_{M2})$ such that:

$$\Delta_{peak} = PNLT_R(k_{M2}) – PNLTM_R$$

4.3.1.3.6 *Determination of the Δ_2 simplified adjustment term to account for change in noise duration*

Section 8.3.4 of Appendix 2 of the Annex specifies that whenever the flight path and/or ground velocity of aircraft differ between test-day and reference conditions, then a duration adjustment should be determined and applied.

This duration adjustment term, Δ_2, comprising two components, accounts for the effects on the EPNL noise duration of differences between the test and reference distance and speed. These components are determined as follows:

$$\Delta_2 \text{ [distance component]} = –7.5 \log (SR(k_M) / SR_R(k_M)) \text{ where:}$$

k_M is the noise data point at which PNLTM occurred; and

$$\Delta_2 \text{ [speed component]} = + 10 \log (V_G / V_{GR}) \text{ where:}$$

V_G and V_{GR} are the test and reference ground speeds of the aircraft, determined from aircraft tracking TSPI data, as determined in 4.3.1.2.

The complete equation for the simplified duration adjustment is:

$$\Delta_2 = –7.5 \log (SR(k_M) / SR_R(k_M)) + 10 \log (V_G / V_{GR})$$

4.3.1.3.7 *Determination of the Δ_3 simplified adjustment term for differences in source noise*

Section 8.3.5 of Appendix 2 of the Annex defines and describes various means of determining a Δ_3 adjustment term to be used in the calculation of reference-condition effective perceived noise level.

Determine the appropriate process, and calculate the value for Δ_3 per section 8.3.5 of Appendix 2 of the Annex, to account for the effects of differences in source noise between test-day and reference conditions.

Application of this adjustment term, Δ_3, is illustrated in 4.3.1.3.8.

4.3.1.3.8 *Determination of the simplified reference-condition effective perceived noise level*

Compute the simplified reference-condition effective perceived noise level, $EPNL_R$, as specified in section 8.3.6 of Appendix 2 of the Annex as follows:

$$EPNL_R = EPNL + \Delta_1 + \Delta_{peak} + \Delta_2 + \Delta_3 \text{ where:}$$

— EPNL is the test-day value for effective perceived noise level, determined in accordance with section 4 of Appendix 2 of the Annex;

— Δ_1 is the simplified adjustment term for the effects of adjusting the PNLTM spectrum to reference conditions as determined in 4.3.1.3.4;

— Δ_{peak} is the secondary peak adjustment term as determined in 4.3.1.3.5;

— Δ_2 is the simplified adjustment term for duration effects as determined in 4.3.1.3.6; and

— Δ_3 is the adjustment term for source noise effects as described in 4.3.1.3.7.

4.3.1.3.9 *Worked example calculations illustrating the simplified method*

[Reserved]

4.3.1.4 ***Computation of EPNL by the integrated method of adjustment***

Section 8.4 of Appendix 2 of the Annex provides specifications for the integrated method. The following procedure illustrates one method for meeting the requirements of section 8.4.

4.3.1.4.1 *Inputs required for performing the integrated method*

The following inputs are required for the integrated method:

a) the one-third octave band spectral time-history representing the measured test-day aircraft noise, SPL(i,k), encompassing at least the test-day EPNL noise duration as defined in section 4 of Appendix 2 of the Annex. Additional guidance is provided in 4.1.3 of Appendix 2 of the Annex;

b) the average atmospheric absorption coefficients, $\alpha(i)$, for each one-third octave band, i, determined for test-day conditions, in dB per 100 metres, as determined from measured test-day meteorological data in accordance with section 7 of Appendix 2 of the Annex. Additional guidance is provided in 4.1.1, under AMC A2 2.2.2.4.1 d) (Calculation of sound attenuation coefficients for the effects of atmospheric absorption);

c) the reference atmospheric absorption coefficients, $\alpha_R(i)$ for each one-third octave band, i, in dB per 100 metres, as determined in accordance with section 7 of Appendix 2 of the Annex. Note that reference conditions for atmospheric absorption are specified in section 3.6 of Chapter 3 of the Annex for aeroplanes being certified under Chapter 3 or Chapter 4 requirements, section 8.6 of Chapter 8 of the Annex for helicopters, and section 13.6 of Chapter 13 of the Annex for tilt-rotors, as a homogenous atmosphere with temperature of 25°C, and relative humidity of 70 per cent;

d) the series of sound propagation distances (in metres) between the aircraft and the microphone at the time of emission of each noise data record, $SR(k)$, as determined in 4.3.1.2;

e) the series of reference sound propagation distances (in metres) between the aircraft and the reference microphone at the time of emission of each reference-condition noise data record, $SR_R(k)$, as determined in 4.3.1.2; and

f) the series of effective durations, $\delta t_R(k)$ for the series of reference-condition noise data records, k, as determined in 4.3.1.2.

4.3.1.4.2 *Adjustment of sound pressure levels to reference conditions*

Adjust each measured test-day one-third octave band SPL in the spectral time history for the effect of spherical spreading (also known as "inverse square law") and the effect of the change in sound attenuation due to atmospheric absorption for differences between the test and reference flight paths, using the equation provided in 8.3.2.1 of Appendix 2 of the Annex:

For all of the one-third octave bands, i, in each of the measured test-day acoustic data records, k:

$$\begin{aligned} SPL_R(i,k) = SPL(i,k) &+ 0.01\,[\alpha(i) - \alpha_R(i)]\,SR(k) \\ &+ 0.01\,\alpha_R(i)\,(SR(k) - SR_R(k)) \\ &+ 20\log(SR(k) / SR_R(k)). \end{aligned}$$

Note.— Sufficient spectra in the measured test-day spectral time history should be adjusted to encompass the integrated reference-condition EPNL noise duration, which may exceed the test-day EPNL noise duration due to adjustments to SPLs that may result in different first and last 10 dB-down points being selected.

4.3.1.4.3 *Determination of reference-condition tone-corrected perceived noise level time-history*

Calculate the reference-condition tone-corrected perceived noise level, $PNLT_R(k)$ for each adjusted spectrum, k, in the spectral time history using the procedures specified in section 4 of Appendix 2 of the Annex, including calculation of perceived noise level, $PNL_R(k)$ and tone-correction factor, $C_R(k)$.

4.3.1.4.4 *Identification of integrated reference-condition maximum tone-corrected perceived noise level*

Using the reference-condition time history of $PNLT_R(k)$ obtained in 4.3.1.4.3, identify the record at which the maximum level occurs, $PNLT_R(k_M)$, and determine and apply the integrated reference-condition bandsharing adjustment, Δ_{BR}, as described in 4.4.2 of Appendix 2 of the Annex, to obtain the bandsharing-adjusted reference $PNLTM_R$:

$$PNLTM_R = PNLT_R(k_M) + \Delta_{BR}$$

Note that due to adjustments for differences between test-day and reference conditions, it is possible that the acoustic data record at which $PNLTM_R$ occurs will be different from the record at which the measured test-day PNLTM occurred. It is also possible that the bandsharing adjustment determined from the integrated reference-condition data set. Δ_{BR}, will be different from the bandsharing adjustment determined from the measured test-day data set, Δ_B.

4.3.1.4.5 *Identification of integrated reference-condition EPNL noise duration*

Using the reference-condition time history of $PNLT_R(k)$ obtained in 4.3.1.4.3, but including the bandsharing-adjusted value for $PNLTM_R$ obtained in 4.3.1.4.4, identify the limits of the reference-condition EPNL noise duration in accordance with 4.5.1 of Appendix 2 of the Annex.

Note that due to adjustments for differences between test-day and reference conditions, the first and last reference-condition 10 dB-down points, k_{FR} and k_{LR} will quite likely be different from the first and last 10 dB-down points for the measured test-day EPNL noise duration, k_F and k_L.

4.3.1.4.6 *Summation of integrated reference-condition EPNL*

Compute the integrated reference-condition effective perceived noise level, $EPNL_R$, by summing the $PNLT_R(k)$ "energy" between the limits, k_{FR} and k_{LR}, of the integrated reference-condition EPNL noise duration, obtained in 4.3.1.4.5, as follows:

$$\mathrm{EPNL_R} = 10\log\left[\left(\frac{1}{\mathrm{t_0}}\right)\sum_{k_{FR}}^{k_{LR}}\left(10^{0.1\,\mathrm{PNLT_R}(k)}\right)\left(\delta \mathrm{t_R}\left(k\right)\right)\right]$$

where:

— the series of $PNLT_R(k)$ values is obtained in 4.3.1.4.3 (substituting as necessary the bandsharing-adjusted value of $PNLTM_R$ in place of the value for $PNLT_R(k_M)$); and

— the effective durations, $\delta t_R(k)$, is obtained in 4.3.1.2.

In practice the adjusted EPNL value takes into account the contributions of sound energy associated with each individual time increment (record), and is calculated from a summation from the first 10 dB-down point, k_{FR}, to the last 10 dB-down point, k_{LR}. Note that due to the effects of the adjustment for differences between test and reference conditions, the effective duration, $\delta t_R(k)$, associated with each record, is not likely to be uniform. Table 4-4 provides an example of how this calculation may be performed.

4.3.1.4.7 *Worked example calculations illustrating the integrated method*

Table 4-4. Example calculation of reference-condition EPNL value when using the integrated method of adjustment

Labels	$PNLT_R(k)$	$\delta t_R(k)$ s	"Energy" $= \left(10^{(0.1 PNLT_R(k))}\right)\delta t_R(k)$
	84.62	0.3950	
	85.84	0.3950	
	85.37	0.3951	
k_{FR}	88.57	0.3951	284254291.2
	88.82	0.3952	301173624.8
	88.03	0.3953	251146317.4
	88.76	0.3954	297191692.3
	87.06	0.3956	201027875.5
	86.92	0.3957	194700044.3
	90.39	0.3960	433206721.0
	89.89	0.3963	386388393.4
	91.00	0.3967	499415710.9
	90.08	0.3973	404686358.5
	89.71	0.3981	372384998.9
	89.61	0.3992	364914006.0
	90.21	0.4009	420761559.6
	91.14	0.4033	524358390.8
	92.10	0.4066	659427985.6
	93.68	0.4108	958584572.0
	94.89	0.4153	1280447955.7
	95.87	0.4196	1621195835.7
	97.06	0.4231	2150022601.5
$PNLTM_R$	97.40	0.4256	2338845959.1
	96.23	0.4273	1793630138.6
	94.73	0.4285	1273358894.6
	92.30	0.4294	729225824.4
	88.75	0.4299	322379520.6
k_{LR}	86.96	0.4304	213733335.2
	85.41	0.4307	
	83.88	0.4309	
	83.01	0.4311	
	Total energy		18276462607.5
	$EPNL_R$ = 10 log (total energy) – 10		92.61892

4.3.2 Jet aeroplanes

4.3.2.1 *Control of noise certification computer program software and documentation related to static-to-flight projection processes*

4.3.2.1.1 *General*

Procedures for computer program software control shall be developed, approved by the certificating authority and maintained and adhered to by each applicant utilizing static-to-flight equivalencies (SFEs). The procedures shall consist of four key elements which, when implemented by the noise certification applicant, shall result in documentation that properly describes and validates the applicable SFE noise certification computer program and data output. Throughout the development of a given aeroplane type, adherence to these procedures will enable the tracking of critical computer programs in order to verify that the initial software design has not been changed without substantiation.

The four key elements of configuration index, software control plan, design description and verification process are described in 4.3.2.1.2.

4.3.2.1.2 *Software control procedures — four key elements*

4.3.2.1.2.1 Configuration index

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

4.3.2.1.2.2 Software control plan

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.

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

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

4.3.2.1.2.3 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.

4.3.2.1.2.4 Verification process

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

4.3.2.1.3 *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 the sound attenuation coefficients for the effects of atmospheric absorption, noy calculations and tone corrections for each main program source code change.

4.3.2.2 ***Identification of spectral irregularities***

4.3.2.2.1 *Introduction*

Spectral irregularities that are not produced by aircraft noise sources may cause tone corrections to be generated when the procedures of 4.3 of Appendix 2 of the Annex 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 (4 ft) above it, interfering with the direct sound energy from the aircraft. The reinforcing and destructive effects of this interference are strongest at lower frequencies, typically 100 Hz to 200 Hz and diminish with increasing frequency. The local peaks in the one-third octave spectra of such signals are termed pseudo-tones. Above 800 Hz this interference effect is usually insufficient to generate a tone correction when the Annex 16 tone correction procedure is used;

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

c) the data processing adjustments such as the background noise adjustment method and the adjustment for sound attenuation due to atmospheric absorption. In the case of the latter, the sound attenuation coefficients, a, given in Reference 17 ascribe values at 4 kHz to the centre frequency of the one-third octave band whereas at 5 kHz the value of “a” is ascribed to the lower pass frequency of the one-third 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 is appropriate. Tone correction factors that result from spectral irregularities (i.e. false tones produced by any of the causes cited above) may be disregarded. This section describes methods that have been approved for detecting and removing the effects of such spectral irregularities. Approval of the use of any of these methods however remains with the certificating authority.

4.3.2.2.2 *Methods for identifying false tones*

4.3.2.2.2.1 Frequency tracking

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

$$f_{\mathrm{DOPP}} = \frac{f}{1 - \mathrm{M} \cos \theta} \ ,$$

where:

— f is the frequency of the noise at source;

— M is the Mach number of the aeroplane; and

— θ is the angle between the flight path in the direction of flight and a line connecting the source and observer at the time of sound emission.

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

4.3.2.2.2.2 Narrow-band analysis

Narrow-band analysis with filter bandwidths narrower than those of one-third octave 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 above.

4.3.2.2.2.3 Microphone mounting height

Comparison of one-third octave spectra of measurements taken using the 1.2 m (4 ft) high microphone and corresponding data obtained from a neighbouring microphone mounted flush on a hard reflecting surface (a configuration similar to that described in 4.4 of Appendix 6 of the Annex) or at a height substantially greater than 1.2 m (4 ft), such as 10 m (33 ft), may be used to identify false tones. Changes to the microphone height alter the interference spectra irregularities from the frequency range of data from the 1.2 m (4 ft) 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 that may be present.

4.3.2.2.2.4 Inspection of noise time-histories

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

4.3.2.2.3 *Treatment of false tones*

When spectral irregularities give rise to false tones that are identified by, for example, the methods described in this section their values, when computed according to Step 9 of the tone correction calculation described in 4.3 of Appendix 2 of the Annex, may be set to zero.

4.3.2.3 ***Noise data adjustments for tests at high altitude test sites***

4.3.2.3.1 *Introduction*

The generation of jet noise is affected by changes in air density. Its generation at higher altitudes may be suppressed due to differences in the engine jet velocity and jet velocity shear effects resulting from the change in air density. Altitude-dependent jet source noise adjustments should be made to take account of this suppression if a test site at or above 366 m (1 200 ft) mean sea level (MSL) is used for the noise test of an aeroplane model that is primarily jet-noise dominated. These adjustments should be made prior to the derivation of PNL described in 4.1.3 a) of Appendix 2 of the Annex, and are in addition to the standard pistonphone barometric pressure adjustment.

4.3.2.3.2 *Altitude dependent jet source noise adjustment*

Flight test site locations at or above 366 m (1 200 ft) MSL, but not above 1 219 m (4 000 ft) MSL, may be approved for noise testing provided the following altitude dependent jet source noise adjustments are applied.

4.3.2.3.2.1 Adjustment procedures

An acceptable jet source noise adjustment is as follows:

a) adjust the measured one-third octave band sound pressure levels for each one-half-second spectrum when using the integrated procedure (see 8.4 of Appendix 2 of the Annex), or the PNLTM one-half-second spectrum when using the simplified procedure (see 8.3 of Appendix 2 of the Annex), by using the following equation:

$$\Delta \mathrm{SPL} = \left[\mathrm{F1} \times \mathrm{F2}\right] \times \left[10 \times \log\left(\rho_B / \rho_A\right) + 50 \times \log\left(c_A / c_B\right) + 10 \times k \times \log\left(U_B / U_A\right)\right]$$

where:

— Subscript A denotes the parameter value at the aeroplane altitude (aeroplane test height plus test site elevation above MSL);

— Subscript B denotes the parameter value at the aeroplane test height

— ΔSPL is the altitude-dependent jet source noise adjustment for each one-third octave band sound pressure level;

— ρ is the density of air in kg/m^3 (lb/ft^3) for a standard atmosphere;

— c is the speed of sound in m/s (ft/s) calculated at ISA + 10°C temperatures;

— k = 8, unless an otherwise empirically derived value is substantiated;

— U is the equivalent relative jet velocity (V_J – V) in m/s (ft/s);

where:

— V_J is the equivalent jet velocity in m/s (ft/s), as defined in Reference 13 and obtained from the engine cycle deck at $N1C_{test}$;

— N1C is the corrected engine fan speed ($N1/\sqrt{\theta_{T2}}$);

— V is the aeroplane test velocity in m/s (ft/s);

— F1 is a directivity factor with values ranging from 0.00 to 1.00 related to sound emission angle (see Figure 4-39); and

— F2 is a frequency dependent factor with values ranging from 0.00 to 1.00 related to the ANSI/ISO one-third octane band number (see Reference 21 and Figure 4-39);

b) for each one-third octave band SPL, arithmetically add the height jet noise adjustment in 4.3.2.3.2.1 a) to the measured SPLs to obtain the altitude-dependent jet source noise adjusted SPLs for the derivation of PNL described in 4.1.3 a) of Appendix 2 of the Annex; and

c) the altitude adjustment is to be applied to all measured test data including approach conditions unless it can be substantiated that the jet noise does not contribute significantly to the total aircraft noise.

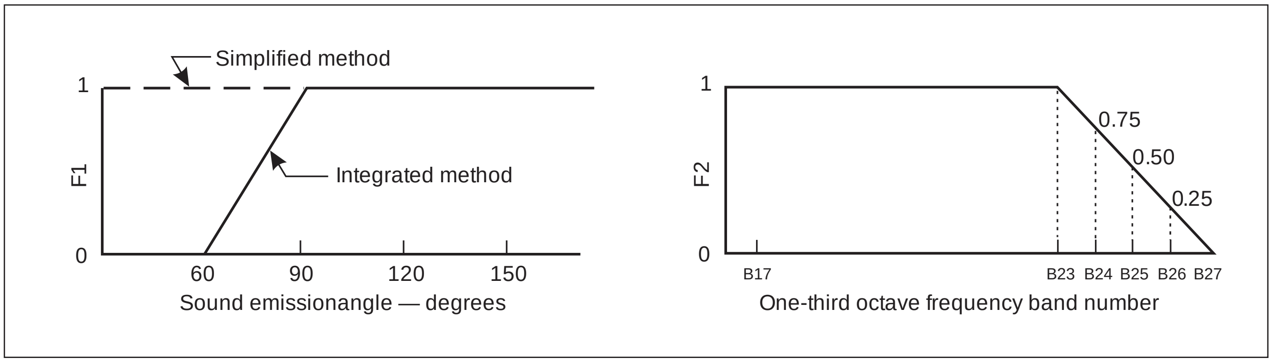


Figure 4-39. Criteria for jet source noise correction

4.3.2.4 ***Acquisition of in-duct and/or near-field data for demonstration of "no acoustical change" (NAC)***

4.3.2.4.1 *General*

Certificating authorities have found it acceptable for applicants to conduct noise tests to evaluate minor engine changes of the types described in 4.2.1.2.2. Frequently the objective for these tests is to provide evidence that the changes involved produce negligible impact on EPNL noise values and may therefore be categorized as NACs relative to the certificated aircraft configuration. Such testing includes component tests, static engine tests in a test cell, near-field microphone measurements, and in-duct dynamic pressure measurements.

4.3.2.4.2 *Guiding principles*

The overall guiding principles to be followed in providing acceptable evidence for substantiation of engine NACs are:

a) the measurements and analyses should adequately model the noise such that small changes in aircraft noise levels can be quantified; and

b) the noise measurement technique and the test environment should not introduce changes to the noise sources that invalidate the predicted small changes in aircraft noise levels.

These guiding principles should be applied in all cases, with details of the approach being justified on a case-by-case basis as appropriate.

Note 1.— It is important that the near-field or in-duct measurements enable a sufficiently accurate prediction of the changes to engine noise in the far field.

Note 2.— It is important that the noise-generating mechanisms of interest are not significantly affected by *the test cell environment. The test cell should have an exhaust collector to minimize re-circulation. There should be insignificant inlet distortion or inflow turbulence, or a turbulence control screen or ICD should be employed to minimize such distortions or turbulence. Test cell measurements might not be appropriate for assessing jet noise changes because of the influence of the test cell on the jet development.*

Note 3.— Care must be taken to ensure the noise source under investigation is not masked by other unrepresentative noise components. While a reduced acoustic standard of components not under investigation might be acceptable in many cases, there are examples where such differences might invalidate the premise of an NAC (e.g. noise from the intake being masked by a hard-walled bypass duct, or significant noise from an overboard air dump contaminating the measured noise).

4.3.2.4.3 *Measurement systems*

Typical measurement systems used to acquire data for substantiation of an engine NAC include:

a) near-field microphones, either in test cells or outdoor facilities;
b) in-duct transducer measurements in the fan inlet or exhaust duct; and

c) core probes to assess combustor or low pressure turbine design changes.

4.3.2.4.4 *Measurement and data analysis procedures*

The measurement and data analysis process should be accomplished on the basis of the following criteria:

a) an adequate array of transducers should be used to ensure that the measurements adequately model the noise. To determine overall changes in sound pressure level, the measured noise levels will typically need to be averaged azimuthally, radially and/or axially in order to avoid false conclusions being drawn from anomalous readings from single transducers;

b) it should be ensured that changes in the local environment (e.g. test cell temperature) do not result in significant anomalies in the measured noise differences;

c) microphones should be mounted on the test cell wall or on the ground or floor but not in the shadow of any support structures or other test hardware;

d) in-duct transducers should be flush-mounted with minimal loss of area of acoustic treatment. Rake-mounted transducers in the flow path should be avoided if they shed wakes that impinge on downstream structures and thereby create significant noise;
e) core probes should be fixed securely to the pylon, boat-tail fairing or other support and not be excessively buffeted by the flow;

f) the specifications of the measurement system and calibration procedures for microphones, recording and reproducing systems should be in accordance with section 3 of Appendix 2 of the Annex. Laboratory calibrations of in-duct transducers and core probes should be conducted before and, if possible, after each test. The dynamic range of the transducers should be sufficient to avoid overload;

g) data should be acquired over the relevant engine operating speeds and for all relevant combinations of engine variables, as specified in the latest version of Reference 14 (see 4.2.1.3.3.1);

h) the interpretation of in-duct measurements should take into account the possibility that decaying or cut-off acoustic waves may be present that may mask changes sensed in the far field of the propagating wave; and

i) two alternative methods could be used in the subsequent analysis of the measured noise levels to demonstrate an NAC:

1) the measured component noise changes could be incorporated into a noise model that predicts the aircraft EPNL. This method has the added value of taking into account in-flight effects and the relative significance of the different noise sources; or

2) in some circumstances, it might be possible to reach the conclusion of an NAC without the need to incorporate the measured component noise changes into a noise model that predicts aircraft EPNL. The measured noise changes could be examined to see if there is no increase in noise levels at any relevant frequency or engine condition.

Generally, noise models that predict the aircraft noise level expressed in EPNL are based on far-field static test data. Consequently, in either analysis it will be necessary to agree with the certificating authority on the method for calculating the impact on far-field static noise resulting from near-field microphone measurements or in-duct transducer measurements. This will normally require sound engineering judgement, seeking out patterns in the data and technical explanations for any observed differences.

Furthermore the statistical (un)certainty in the data should be considered. For example if statistical analysis shows that the uncertainty in the data is large and the differences are small, then no conclusions can be drawn from the data. On the other hand if the tests show large decreases in noise levels that outweigh the uncertainty in the data it may be possible to conclude, with reasonable certainty, that the changed engine is indeed quieter than the original engine.

Chapter 5

GUIDELINES FOR PROPELLER-DRIVEN AEROPLANES NOT EXCEEDING 8 618 KG EVALUATED UNDER APPENDIX 6 OF ANNEX 16, VOLUME I

5.1 EXPLANATORY INFORMATION

5.1.1 Noise measurements

See 3.1 for technical procedures generally applicable for noise certification tests of all aircraft types including those evaluated under the provisions of Appendix 6 of the Annex. In the following section procedures specific to Appendix 6 are presented.

5.1.2 Noise certification test and measurement conditions

GM A6 2.2.2
[Meteorological conditions]

1) *Atmospheric conditions*

Atmospheric conditions can affect the generation and propagation of sound for non-reference helical tip Mach numbers (see 5.2.1 of Appendix 6 of the Annex). Propellers generate higher noise levels at higher propeller helical tip Mach numbers. Usually the actual tip velocity is close to reference propeller-tip velocity, but the speed of sound is a function of air temperature that is often different than the reference value. Off-reference tip Mach numbers can occur because of off-reference air temperature. The Annex specifies the need for correction for non-reference tip Mach numbers under most circumstances. However, limiting the permissible test temperature range reduces the potential magnitude of this correction. Corrections are also required to account for non-reference atmospheric absorption of sound. The magnitude of this correction is also limited by restricting the range of permissible temperature and relative humidity.

2) *Non-uniform atmosphere*

The atmosphere between the source (i.e. aeroplane, propeller and/or exhaust) and the microphone is not uniform. There can be strong temperature gradients, positive and negative, variations in relative humidity and variations in wind. Turbulence is also associated with strong winds, which can cause irregular sound propagation. Corrections are not required to account for wind. The wind limits provide only a means of determining the acceptability of the data.

3) *Weather monitoring*

Based on the above considerations, weather conditions should be monitored. Procedures used in the noise certification process for transport category aeroplanes and turbojet-powered aeroplanes call for measurement of the weather conditions between the ground and the height at which the aeroplane is flying (see 2.2.2.4.1 b) of Appendix 2 of the Annex). The absorption of sound in air can then be computed based on these measurements. This process requires an appreciable investment of time and resources. For light propeller-driven aeroplanes, the magnitude of the adjustment for atmospheric absorption is less than that for jet aeroplanes. An adjustment procedure based on measurements of the weather near the surface is therefore considered sufficient and more appropriate for aeroplanes covered by this section.

4) *Temperature inversions*

The effects of inversions and anomalous wind conditions are difficult to quantify. When temperature inversions are present (i.e. when the air temperature increases with height over any portion of the atmosphere between the ground and the aeroplane) flight conditions may be unstable, which hampers the ability of the pilot to set up a consistent, stabilized climb within the permitted operational tolerances. Also, under these conditions, it is possible to have a situation in which the surface temperature and relative humidity meet the permissible test criteria but the conditions aloft are much drier, with consequent high sound absorption characteristics and the possibility of underestimating the noise level. The noise spectrum of propeller-driven aeroplanes contains relatively less high frequency noise than that of jet aeroplanes, so the effects may not be very significant unless there is a severe inversion.

AMC A6 2.2.2
[Atmospheric measurements]

1) *General weather measurements*

The applicant should measure weather conditions near the surface and in the vicinity of the noise measuring point. The acceptability of noise data is contingent on the conditions being within the specified limits of 2.2.2 of Appendix 6 of the Annex. These measurements are to be made at a height between 1.2 m (4 ft) and 10 m (33 ft) above ground level. This allows the use of hand-held equipment but does not preclude the use of more complex equipment of the type identified in Appendix 2 of the Annex if the applicant so chooses. The weather data may be recorded on a chart, or a record of the observations, witnessed by the certificating authority, may be kept.

2) *Wind*

Consistent with the less complex requirements for small propeller-driven aeroplanes, wind measurements may be made using a hand-held device if its specifications comply with the provisions of 2.2.2.1 of Appendix 2 of the Annex. If the device used does not provide enough information to compute the crosswind, then the wind in any direction should be limited to the crosswind limit of 2.6 m/s (5 kt). The wind limits are based on a 30-second average.

3) *Temperature and relative humidity limits*

Noise data are acceptable only if the air temperature is in the range of 2°C (36°F) to 35°C (95°F), and the relative humidity is in the range of 20 to 95 per cent. Temperature and relative humidity may be measured with a psychrometer, a device that measures wet and dry bulb temperatures of the air. Relative humidity is then computed from these temperatures. Sufficient measurements should be made to determine all adjustments specified by Appendix 6 of the Annex. Persons responsible for performing the test should be alert to changes in the conditions. At a minimum, measurements should be made immediately before the first run in a series and immediately after the last run. This interval should not exceed more than one hour because of the requirement for adjustment of the aeroplane test mass due to fuel loss. In marginal or changing conditions, shorter intervals would be more appropriate.

4) *Anomalous winds*

The presence of anomalous wind conditions may be assessed by noting the airspeed variation as the aeroplane climbs. If the wind is uniform or changes speed or direction slowly with altitude, there is no difficulty in maintaining a constant climb speed. If there are strong variations in the wind (i.e. wind shear) or rising and descending air, there will be variations in airspeed that are not easily controllable. Variations of ±2.6 m/s (±5 kt) during the overflight relative to the reference velocity, V_Y, are permitted by Appendix 6 of the Annex, and this criterion may be used to evaluate the presence of anomalous wind conditions.

5) *Air temperature measurements versus altitude*

At the beginning of the test and, if considered necessary, at intervals during the test, an observer on the test aeroplane may consider monitoring the air temperature during a climb. This climb may be a noise data–recording climb or may be dedicated to temperature measurement. The information shall be assessed if a judgement is to be made about the acceptability of the conditions for noise measurements. The presence of anomalous wind conditions can be assessed during the data acquisition.

GM A6 2.3.5
[Aeroplane flight path]

1) *Aeroplane position*

Chapter 10 of the Annex specifies determination of the noise level at a single location relative to the start of take-off roll. Limits on the permissible deviation from the reference flight path (see Figure A6-1 of Appendix 6 of the Annex) are specified for the flight tests. These limits are based on the ability to obtain consistent, representative results, without placing excessive restrictions on the flight test. The initial take-off mass should be equal to the maximum approved take-off mass, and after an hour of flight time, the mass is to be increased back to maximum to account for fuel burn. This procedure ensures that the flight parameters, primarily angle-of-attack, do not vary significantly from the reference. The aeroplane position is to be approved by the certificating authority for each test overflight.

5.1.3 Noise unit definition

GM A6 3.0
[A-weighting]

1) *Basis of measurement*

The A-weighting correction curve has been precisely defined by national and international standards for the measurement of sound, such as environmental noise, and is a standard feature in sound level meters and other sound analysis equipment used for noise assessments.

5.1.4 Measurement of aeroplane noise received on the ground

GM A6 4.3.1
[Recording systems]

1) *Audio recorders*

An audio recorder can be used to preserve a complete acoustical record of the events. If there are questions about the data observed during the tests, the recorded data can be replayed, multiple times if necessary, to verify the results. A more detailed analysis of the aeroplane noise signal may also be useful to the applicant for research and development purposes.

2) *Graphic level recorders*

A graphic level recorder can be used to provide a permanent record of the noise levels, but no replay or reproduction of the acoustical signal is possible.

3) *Sound level meters*

The record that results from the use of a sound level meter depends on the design features of the instrument. The least complex instrument uses an electromechanical metering mechanism, requiring the operator to observe the highest level indicated by the moving needle in the meter display during each event. Other, more complex instruments can be set to hold the maximum noise level reached during each event and show this level on a digital display. Some currently available digital units are capable of storing entire time-histories of noise levels for multiple runs. These histories can be recalled to the instrument's display, transmitted to a printer or downloaded to a computer.

AMC A6 4.3.1
[Recording systems]

1) *Audio recorders*

One method is to record each noise event using an audio recorder. This recorded data can be played back and analysed as much as necessary to verify that consistent results have been obtained.

2) *Other methods*

Other methods include the following:

a) reading graphic level recorder charts;

b) reading a sound level meter in the field as the event occurs and keeping a handwritten log in ink; and

c) printing, or transferring to a personal computer, the entire time history after the test has been completed.

Appropriate measures should be taken to ensure the validity of the data, and their use is subject to approval by the certificating authority.

GM A6 4.3.4
[Noise characteristics]

1) *Filtered noise level and meter response speed*

The noise level from each flyover test should be measured in terms of the maximum A-weighted sound level, in decibel (dB(A)) units, using an A-weighting filter with dynamic characteristics (meter response characteristics) designated as "S" (for "slow") as defined in Reference 4 and specified in section 3 of Appendix 6 of the Annex. The slow response results in an effective two-second averaging period (i.e. one-second time constant), which should be used in Appendix 6 noise tests.

2) *Maximum sound level*

The measured or indicated A-weighted sound level will increase as the aeroplane approaches the measurement site and will decrease after the aeroplane passes over the site. The highest value of the A-weighted sound level that occurs during the overflight is called the maximum A-weighted sound level. This is the value that should be measured during each test.

Note.— This maximum value may not occur at the exact moment when the aeroplane is directly over the microphone. It usually occurs slightly before or after the aeroplane reaches the overhead position due to the directivity characteristics of propeller, engine and exhaust noise emissions.

GM A6 4.3.5
[Measurement system sensitivity]

1) *Noise level variability*

There can be variability in the noise levels indicated by the test equipment, primarily due to environmental factors and the internal warm-up that is required by most types of equipment. Occasionally, there may be other changes due to cable problems or even equipment damage. Proper use of acoustic calibration devices can help identify such occurrences.

AMC A6 4.3.5
[Calibration process]

1) *Equipment calibration*

A suitable sound calibrator should be used to provide a reference sound level. This is usually accomplished by placing the calibrator on the microphone and adjusting the gain of the measuring system so that the reading corresponds to the known sound level of the calibrator. Initial, final and periodic calibrations should be used to verify that any changes in sensitivity are identified. It is important that the manufacturer's recommended system warm-up time be observed in the field prior to equipment calibration. Calibration equipment should be identified in the test plan and is to be approved by the certificating authority.

GM A6 4.4.1
[Microphone configuration]

1) *Ground plane microphone*

The specified ground plane microphone configuration greatly minimizes the interference effects of reflected sound waves inherent in pole-mounted microphone installations. For a 1.2 m (4 ft) microphone, such effects typically occur in the frequency region that is most significant for propeller-driven aircraft noise.

2) *Microphone sensitivity*

The specified ground plane configuration places the microphone diaphragm into an effective sound pressure field for the frequency range of interest. Microphones designed for uniform pressure response are appropriate for use in such installations.

AMC No. 1 A6 4.4.1
[Microphone configuration]

1) *Inverted microphone*

The inverted microphone set-up shown in Figure 5-1 is an example of the design and construction of the microphone holder and the ground plate. The legs of the microphone holder should be firmly attached to the plate so that the microphone holder does not vibrate during the test. The plate should be painted white to reflect the sun’s rays, as such reflection will reduce the thermal effects on the microphone-sensing element. A metal spacer is a practical tool to use in setting the space between the microphone diaphragm and the ground plate. The spacer thickness should be 7 mm minus the space between the microphone protective grid and the microphone diaphragm.

2) *Microphone placement*

The spacing of the microphone diaphragm relative to the plate is critical, since it should be inserted completely within the effective sound pressure field, and the depth of this field varies with frequency and sensor size. For frequencies of interest, 7 mm spacing has been determined to provide the best compromise of associated technical considerations.

AMC No. 2 A6 4.4.1
[Microphone installation]

1) *Plate installation in local ground surface*

Care should be taken during installation to ensure that the ground surface beneath the plate is level and contains no voids or gaps. One way to achieve this is by pressing the plate into the ground surface at the desired location, applying slight pressure, then removing the plate to determine if any areas under the plate are recessed. These recesses can then be filled in with loose material, such as sand or soil, to obtain a level, uniform underlying surface. Care should also be taken to ensure that the edges of the plate are flush with the surrounding ground surface. This is especially important for plates that are thicker than the specified minimum of 2.5 mm.

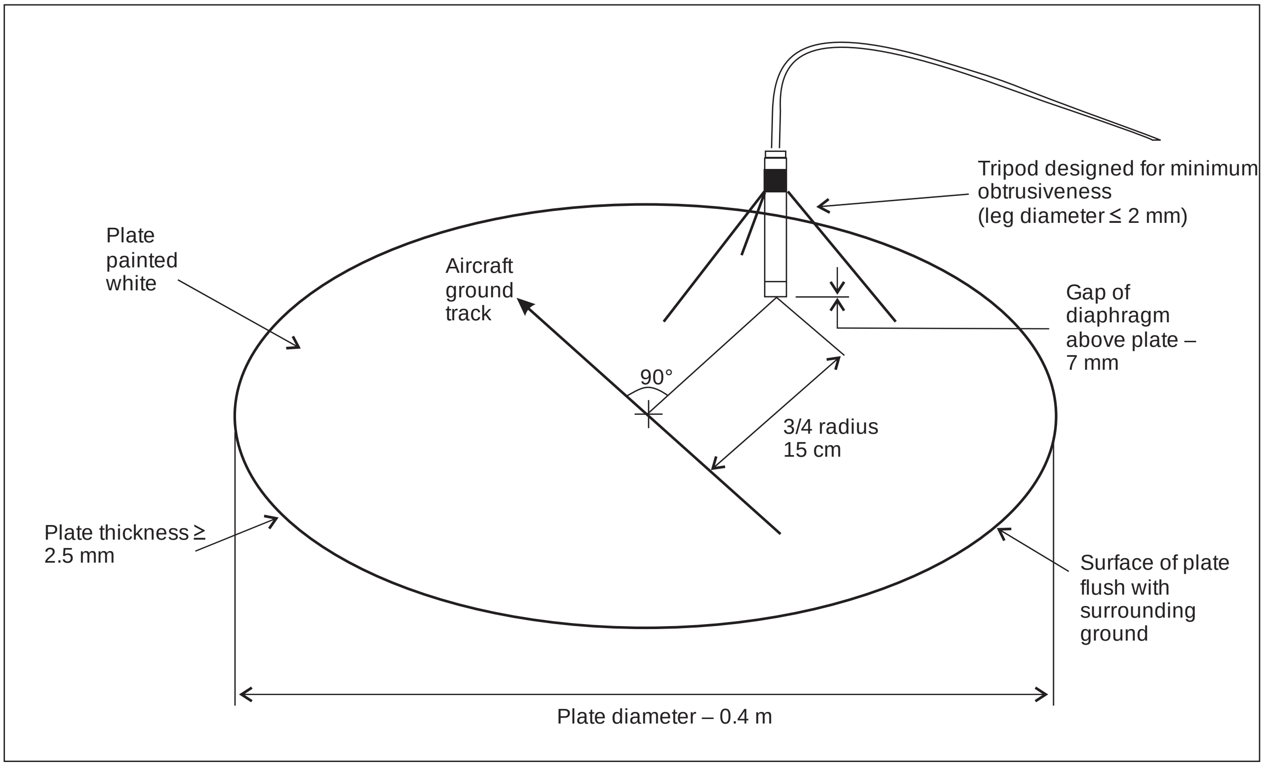


Figure 5-1. Configuration for one-half-inch inverted microphone

In some cases it may be appropriate to moisten the soil with water immediately before installation to allow the surface to mould itself around the plate. In such cases, acoustical measurements should not be performed until the ground has dried.

2) *Design and construction of microphone support*

The support should be designed so that it minimizes any potential interference with sound waves from the aircraft arriving in the vicinity of the microphone. If a spider-like structure such as that in Figure 5-1 is used, the number of legs should be limited to three or four. As specified in the figure, the legs should be no larger than 2 mm in diameter. Ideally the support collar should be as small as possible, and it should also implement some sort of tightening device, such as a set screw, to facilitate adjustment of the microphone diaphragm height above the plate. The support should be stable and should orient the microphone in such a way that the diaphragm is parallel to the plate.

3) *Cable support*

In some cases, it may be desirable to provide additional support to the microphone cable as it leads away from the plate. A metal rod or similar sort of support may be used for this purpose. Any such support should be as small as possible and located as far away from the plate as is practical. The microphone cable should lead directly away from the plate without crossing above any more of the plate's surface than is necessary.

4) *Windscreens*

Consideration should be given to using windscreens when wind speed exceeds 2.6 m/s (5 kt) (see 5.2.2).

AMC A6 4.4.4
[Background noise alleviation]

1) *Increased aeroplane noise*

If a site with lower noise levels cannot be used, it may be necessary to fly the aeroplane so that the target height over the microphone is less than it would be at the reference microphone station (2 500 m (8 202 ft) from the start of the take-off roll). In this case, the aeroplane height at the microphone location is likely to be outside the ±20 per cent tolerance specified in 2.3.5 of Appendix 6 of the Annex. Adjustment of data to reference conditions should be performed in an approved manner.

5.1.5 Adjustment to test results

GM A6 5.2.1 a)
[Atmospheric absorption adjustment]

1) *Atmospheric absorption*

The temperature and relative humidity of the air affect the sound propagation. This correction accounts for the difference in atmospheric absorption along the sound propagation path that occurs between temperature and relative humidity under noise certification test conditions and temperature and relative humidity under reference conditions 15ºC (59°F) and 70 per cent relative humidity (see 5.2.2 of Appendix 6 of the Annex for additional atmospheric absorption correction information).

GM A6 5.2.1 b)
[Noise path adjustment]

1) *Noise path length*

The aeroplane test limitations are that the height over the microphone shall be within ±20 per cent of the reference height and that the lateral position shall be within ±10° of the vertical. The noise path length correction adjusts the measured noise levels for the difference in noise path length between actual noise test conditions and reference conditions (see 5.2.2 of Appendix 6 of the Annex for additional path length correction information).

GM A6 5.2.1 c)
[Noise source adjustment]

1) *Helical tip Mach number*

The noise generated by a propeller-driven aeroplane depends on the rotational speed of the tip of the propeller, more specifically the helical tip Mach number. Data corrections are based on the relationship between the helical tip Mach numbers determined for test and reference conditions (see 5.2.4).

Note.— The reference helical tip Mach number, $M_{HR,}$ *is the one corresponding to the reference* *conditions above the measurement point.*

GM A6 5.2.1 d)
[Noise source adjustment]

1) *Engine power*

Corrections are required to account for non-reference engine power settings that are used during noise certification tests. The procedures for determining the engine power to be used in the calculations depend on the design characteristics of the engine-propeller combination. In most cases, this power is not published and does not have to be determined for airworthiness purposes. It is therefore necessary to determine the power for noise certification purposes (see 5.2.4).

5.1.6 Reporting of data to the certificating authority and validity of results

GM A6 6.1.3
[Reporting of meteorological data]

1) *Interpretation of "each test"*

For clarification, this refers to each test series (i.e. test) and each test overflight (i.e. run). The meteorological measurements should be made at the time of each test run, since each noise measurement will be corrected by use of the meteorological data.

2) *Wind measurement*

The provisions of 2.2.2 c) of Appendix 6 of the Annex set the limits on testing, based on a 30-second average wind speed, not to exceed 5.1 m/s (10 kt), with a 2.6 m/s (5 kt) crosswind limitation. There are no additional limitations based on the surface wind.

AMC A6 6.1.5
[Reporting of aeroplane information]

1) *Equipment calibrations*

All equipment utilized to determine the required parameters should be calibrated, and the calibrations are to be applied before being reported to the certificating authority in the test report and before being used to make reference aeroplane corrections. The temperature at the aeroplane height should be acquired for tip Mach number correction.

2) *Mechanical tachometers*

Separate validation of the in-flight reading should be made if a mechanical tachometer is used because mechanical tachometers are subject to potential indicating errors as a result of the cable drive system.

AMC A6 6.2.1
[Reference noise levels/confidence intervals]

1) *Average noise level calculations*

Calculation of average noise and associated confidence intervals should be accomplished as described in 3.5.

When the 90 per cent confidence limit calculated using data from six or more test flights is within ±1.5 dB(A), then the average corrected noise level, average L_{ASmax}, resulting from the validated data can be used to determine conformity with the maximum noise levels specified in 10.4 of Chapter 10 of the Annex.

GM A6 6.2.2
[Confidence limit compliance]

1) *Confidence limit exceedance*

If the 90 per cent confidence limit does not satisfy the ±1.5 dB(A) standard, additional test data points should be obtained, increasing the number of events until the confidence limit is reduced to ±1.5 dB(A). The variability of data obtained under controlled conditions should be substantially less than ±1.5 dB(A). If the 90 per cent confidence interval is near or above the permitted limit, the approved test procedures and/or correction procedures should be carefully reviewed.

5.2 EQUIVALENT PROCEDURES INFORMATION

The procedures described in this chapter have been used as equivalent in stringency for propeller-driven aeroplanes with maximum certificated take-off mass not exceeding 8 618 kg, as provided in Chapters 6 and 10 of the Annex.

5.2.1 Installation of add-on silencers (mufflers)

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

The aeroplane performance characteristics must be re-evaluated after the installation of the add-on silencer (muffler). The type design change represented by the silencer (muffler) installation can be accepted as a no-acoustical change (NAC) (2.3) for compliance with Chapter 6 or 10 of the Annex if the following conditions are verified to the satisfaction of the certificating authority:

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

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

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

5.2.2 Guidance on use of a windscreen

For noise certification tests conducted according to Chapter 10 of the Annex, the microphone shall be installed in accordance with 4.4.1 of Appendix 6, which describes how the microphone shall be mounted in an inverted position so that the microphone diaphragm is 7 mm (0.3 in) above and parallel to a circular metal plate. With this configuration, many certificating authorities have approved the use of a windscreen in order to minimize wind- and turbulence-induced pseudo-sound levels and to protect the microphone during the test.

A windscreen prepared and used in the following manner will cause no significant effect on the test result. The windscreen must be made from a commercially available spherical foam windscreen cut into a hemispherical shape in order to accommodate the microphone over the plate. In preparing the hemispherical windscreen, the following points shall be ensured:

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

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

5.2.3 Take-off test and reference procedures

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

The take-off reference profile is used to compute the altitude and speed of the aircraft passing over the microphone on a standard day. The requirements for this profile are contained in 10.5.2 of Chapter 10 of the Annex. They require that the first segment be computed by using airworthiness approved data, assuming take-off power is used from the brake-release point to 15 m (50 ft) above the runway. The second segment is assumed to begin precisely at the end of the first segment with the aeroplane in a climb configuration, with gear up and climb flaps, and operating at the certificated speed for best rate of climb, V_Y (see Figure 5-2).

A worked example of the calculation of reference flyover height and reference conditions for correction of source noise for aeroplanes certificated according to the Standards of Chapter 10 of the Annex is presented in 5.3.1.

The requirements for aeroplane test procedures are contained in 10.6 of Chapter 10 and 2.3 of Appendix 6 of the Annex. They basically refer only to test tolerances and approval of test plans by certificating authorities.

Figure 5-2 illustrates the difference between the test and reference procedures. Note that the actual flight test path need not include a complete take-off from a standing condition. Rather, it assumes that a flight path intercept technique is used. As with the turbojet, helicopter and tilt-rotor standards, the aeroplane should be flown to intersect the second phase (i.e. segment) climb path at the right speed and angle of climb when going over the microphone within 20 per cent of the reference height.

The take-off reference procedure defined in Chapter 10 of the Annex requires that the second phase of the procedure shall be flown at the best rate of climb speed V_Y. The aeroplane testing procedures described in Appendix 6 of the Annex require that the flight test shall be conducted at V_Y. The reference height to which the measured noise levels are to be corrected is calculated from the climb rate corresponding to V_Y. Recent changes to the airworthiness requirements have eliminated the need to determine V_Y for small propeller-driven aeroplanes. In this case applicants will nevertheless have to determine V_Y for the purpose of showing compliance with Chapter 10 of the Annex. If the minimum airworthiness approved climb speed is greater than V_Y then this speed shall be used and noted in the AFM.

Applicants may alternatively show compliance with Chapter 10 of the Annex at the climb speed for which the AFM performance information is calculated provided they demonstrate, to the satisfaction of the certificating authority, that the resulting noise level is not less than would have been obtained using V_Y.

5.2.4 Source noise adjustments

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

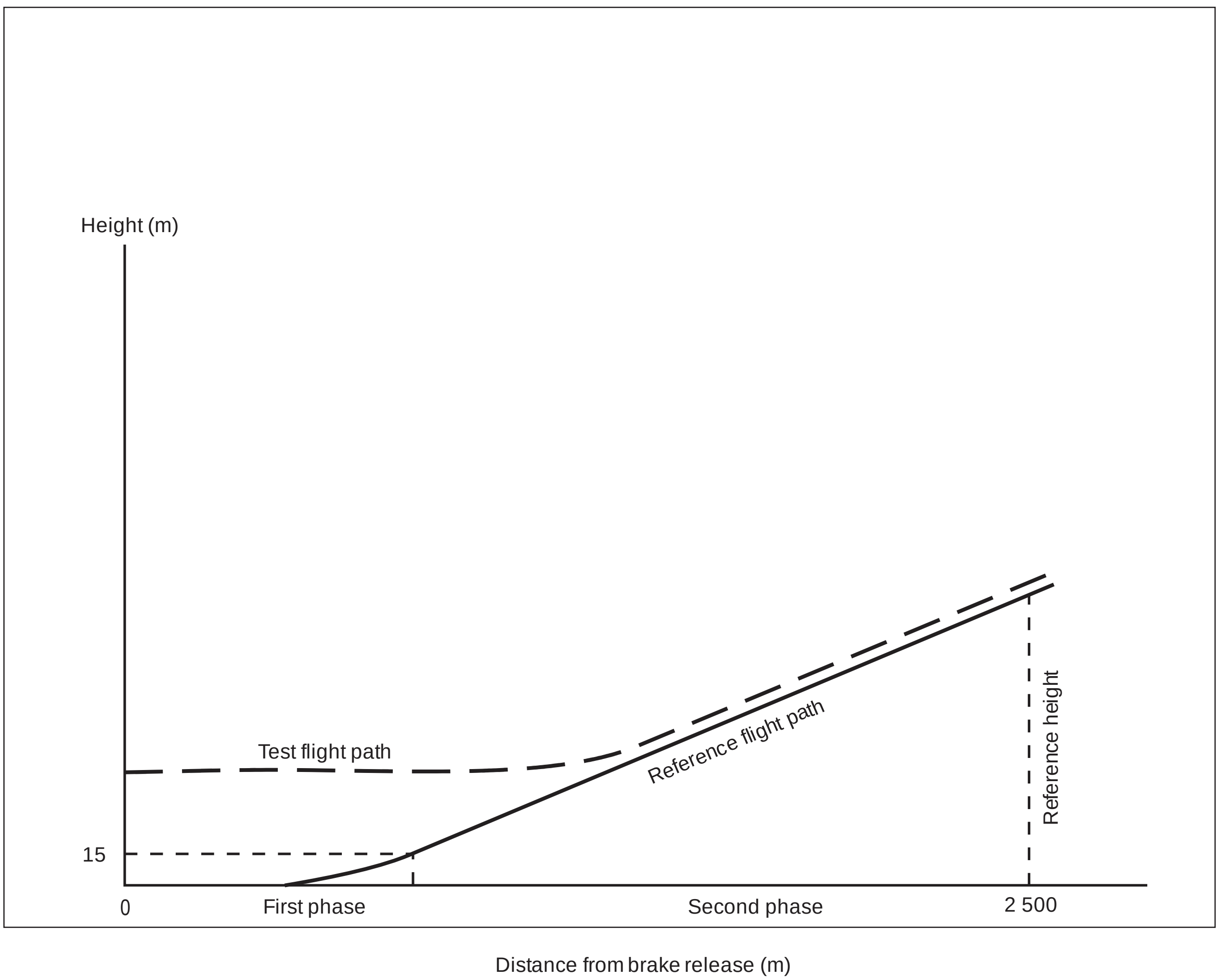


Figure 5-2. Typical test and reference profiles

5.2.4.1 ***Fixed pitch propellers***

For aeroplanes fitted with fixed pitch propellers demonstrating compliance with Chapter 6 of the Annex, source noise sensitivity curves are developed from data taken by measuring the noise level for the aeroplane flying at 300 m (984 ft) (see 6.5.2 of Chapter 6 of the Annex) at the propeller speed for maximum continuous power (N_{MCP}).

Aeroplanes demonstrating compliance with Chapter 10 of the Annex should be flown according to 2.3 of Appendix 6 of the Annex. In this way, the aircraft overflies the microphone at the reference height, H_R, defined in 10.5.2 of Chapter 10 of the Annex, the best rate of climb speed, V_Y, and at the propeller speed, N_{MAX}, corresponding to that defined in 10.5.2 d) of the "second phase" of 10.5.2 of Chapter 10 of the Annex.

For both Chapter 6 and Chapter 10 aeroplanes, 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_{ASmax}, is plotted against the propeller helical tip Mach number, M_H, in order to obtain the curve from which the source noise correction may be derived.

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

5.2.4.2 ***Variable pitch propellers***

For variable pitch propellers, the source noise sensitivity curves are developed from data taken with the aircraft flying over a range of propeller speeds, typically three, at a fixed torque or MAP in a manner similar to that described in 5.2.4.1 where N_{MCP} or N_{MAX} would in this case be the maximum propeller speed at the maximum permitted torque or MAP. This is repeated for two lower torque or MAP values in order to establish a carpet plot of maximum A-weighted noise levels against propeller speed and torque, MAP or SHP.

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

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, which is normally presented for a range of engine speeds under ISA and sea level conditions, in order to establish the engine power level under the test conditions of ambient temperature and air density. The correction is as follows:

a) for normally aspirated engines:

$$P = P_0\left[\left(T_0/T\right)^{1/2}\right]\left[\left(\sigma - 0.117\right)/0.883\right];\ \text{and}$$

b) for turbo-charged engines:

$$P = P_0\left[\left(T_0/T\right)^{1/2}\right],$$

where:

— P and P_0 are the test and reference engine powers;

— T and T_0 are the test and reference ambient temperatures in kelvin; and

— σ is the air density ratio.

Note.— In this context reference denotes the manufacturer's reference conditions for which the engine SHP is known.

5.2.5 No-acoustical change guidance for derived versions of propeller-driven aeroplanes certificated according to Chapter 10

After the certification in their basic configuration, small propeller-driven aeroplanes are often modified, either by a TC change of the TC holder or by an STC from a supplier. These changes can be of a different nature such as an increase or decrease in maximum take-off mass, engine change, power change, propeller change, installation of vortex generators, fitting of winglets or external mounted equipment (cargo boxes, floats, etc.). With regard to noise and depending on their nature, some changes might have to demonstrate compliance with the applicable requirements by a new flight test, others by re-evaluation of the original noise flights or by demonstrating a no-acoustical change.

The propeller and the engine are the main noise sources of small propeller-driven aeroplanes. Parameters like the diameter, the number of blades, the rpm, the pitch, the blade tip shape or the geometry could have an impact on the propeller noise signature. As for the engine, noise signature could change by modifying the rotor assembly or the exhaust.

Several sections refer to the determination of a new reference height due to a change in performance data, here D_{15}, V_Y and R/C. New performance data are accepted for the recalculation only if they are established by a method approved by the certificating authority.

The following sections are intended to provide guidance for applicants and certificating authorities concerning an NAC demonstration.

5.2.5.1 *No-acoustical change guidance for aeroplanes fitted with fixed pitch propellers*

(Reserved)

Note.— This guidance is limited to variable pitch propellers only. According to 10.5.2 of Chapter 10 of the Annex, take-off rpm shall be maintained throughout the noise test runs. During climb at the best rate of climb speed, the fixed pitch propeller can generally not reach its maximum operating rpm value. Therefore the reference propeller speed is defined to be the average propeller rpm calculated from all valid runs. Changing the performance (e.g. due to an engine change or a change in mass) might change the average rpm adversely. Currently the amount of change in the propeller rpm for a fixed pitch propeller cannot be estimated analytically.

5.2.5.2 *No-acoustical change guidance for aeroplanes fitted with variable pitch propellers*

5.2.5.2.1 *Engine change without power change*

The engine is one of the main noise sources of the aeroplane. Changes to the engine can take many forms. They vary from small changes within one engine family, normally addressed by different characters within the engine designation, to a complete re-engine. In the latter case the compliance demonstration can in general be achieved only by new noise flight tests. In the former case it is often obvious that the change has no-acoustical impact, and a simple statement should suffice to demonstrate that the change is not acoustically significant.

5.2.5.2.2 *Power increase without changing the propeller rpm*

Increasing the power output of an engine without changing the take-off mass will increase the engine noise level at source but also improve the take-off performance. A method subject to the approval by the certificating authority can be applied to evaluate the increase in engine noise source. This increase in engine noise source may be offset by the higher reference height. Take-off distance is shortened, the climb rate is increased and therefore the flyover height over the microphone is increased. If it can be shown that this increase in reference flyover height offsets the increase in engine source noise, the change in engine power may be considered as an NAC.

An NAC is acceptable if it can be demonstrated that a minimum of six valid flights are within the “new” height window.

The effect of angle-of-attack changes may be included in the analysis by a method approved by the authority. The method must be robust enough to account for the effects of performance and angle-of-attack changes on noise levels. If the analysis method shows that the noise level does not increase then the noise level of the unmodified aeroplane can be applied. Otherwise new testing should be required.

Note.— Paragraph 10.5.2 of Chapter 10 of the Annex defines that the microphone has to be passed at maximum take-off power. If source noise sensitivity curves are established in accordance with the procedure laid down in 5.2.4 of this chapter the noise level can be adjusted up to the highest power covered by the sensitivity curve. In such a case the power correction determined by the sensitivity curve should be used instead of the general adjustment $\Delta_3 = k_3 \log (P_0 / P)$.

5.2.5.2.3 *Change in mass*

According to 2.3.2 of Appendix 6 of the Annex, the flight tests shall be initiated at the maximum take-off mass. Only increases in take-off mass up to the maximum actually flown during the original flight tests can be accepted without new flight tests. If it can be demonstrated that a further mass increase and the corresponding loss of performance do not adversely affect the noise level by more than 0.1 dB(A), the certificated noise level may be assigned to this mass without additional flight tests.

A change in the mass of the aircraft will lead to different performance characteristics. A new reference height with the new performance parameters has to be determined to demonstrate the influence on the noise level. Possible impact on the propeller speed should be taken into account.

Similar to the previous section, the effect of angle-of-attack changes may be included in the analysis by a method approved by the certificating authority.

5.2.5.2.4 *Drag change*

While a change in drag generally has no direct impact on the noise at source, it may have an indirect effect on noise level through a change in performance.

A drag change will in general be introduced by modifications such as the fitting of cargo pods or external fuel tanks, larger tires, floats, etc. In most cases, the change in aerodynamic noise can be shown to be negligible for small propeller-driven aeroplanes. However, there may be cases where the aerodynamic noise generated by the modification has to be addressed. The drag change might change the performance characteristics of the aircraft D_{15}, V_Y and/or R/C leading to a change in reference flyover height. The performance characteristics defined in the AFM are approved by the performance experts of the certificating authority. In some cases the performance experts agree to apply the former performance parameters to the modified aircraft if the applicant can demonstrate that the performance is not worse than the one for the basic aircraft.

Three different situations have to be considered:

a) the performance characteristics are better than those of the parent aircraft;

b) the performance characteristics are identical to those of the parent aircraft; and

c) the performance characteristics are worse than those of the parent aircraft.

With regard to noise these three situations should be dealt with as follows:

a) in the case of situation a), independent of whether the applicant decides to maintain the old performance data or to document the better performance in the AFM, an NAC can be granted and the noise level for the parent version can be applied to the modified aircraft;

b) in the case of situation b), the noise level for the parent version can be applied to the modified aircraft without further investigation; and

c) in the case of situation c), in general a new flight test is required.

5.2.5.2.5 *Different blade count propeller*

The effect of changing the number of the propeller blades on the noise level is difficult to determine by analytical procedures. Typically the applicant is obliged to perform a new flight test. Propeller noise prediction routines are highly sophisticated requiring extensive data sets that can in general be provided only by the propeller manufacturer. The use of such propeller noise prediction routines has to be acceptable to the certificating authority to demonstrate an NAC.

5.2.5.2.6 *Different blade tip shape*

In general rounded tips are quieter than squared ones. The change from squared to rounded blade tips can be accepted as an NAC if the rpm and diameter remain the same.

5.2.5.3 ***Methods for demonstrating a no-acoustical change***

The technical procedures presented in this section are examples of procedures that certificating authorities have found to be acceptable for use with small propeller-driven aeroplanes with variable pitch (constant speed) propellers certificated to Chapter 10 of the Annex. Other procedures may be acceptable. In all cases the applicant is responsible for proposing the means, including flight tests, for demonstrating that modification(s) will not adversely affect the noise level of an aeroplane and can therefore be considered as a no-acoustical change (see 2.3). The procedures described in this section are intended only for the purpose of demonstrating a no-acoustical change. The procedures are not acceptable for demonstrating certification noise levels.

5.2.5.3.1 *Procedures*

The methods described in this section include actual flight test measurement and analytical procedures which, while differing from the methods specified in Chapter 10 and Appendix 6 of the Annex, are nevertheless considered to be equivalent. The methods are intended to demonstrate whether specific aeroplane modifications can be considered as no-acoustical changes without the need for a new noise certification measurement campaign. Whatever methods are used must be approved by the certificating authority.

5.2.5.3.2 *Factors that might adversely affect the noise level*

Certification noise levels acquired according to the Chapter 10 test procedures are dependent on both the basic noise generating characteristics of the installed propeller/engine and the aircraft's take-off and climb performance. The following list presents examples of changes that might have an adverse effect on the aircraft's noise levels:

a) change that brings about a decrease in the height of the aeroplane at the reference distance of 2 500 m (8 202 ft) from the start of take-off roll under the reference conditions and following reference procedures;

b) increase in engine power;

c) removal or alteration of exhaust mufflers;

d) increase in propeller helical tip Mach number (e.g. from increase in propeller diameter and/or rotational speed);

e) change in propeller geometry;

f) decrease in aeroplane climb path angle/decrease in rate of climb;

g) increase in aeroplane drag;

h) increase in propeller inflow angle;

i) change in the number of propeller blades; and

j) change from a fixed pitch propeller to a variable pitch propeller (or vice versa).

If a "no-acoustical change" is claimed for a suite of modifications, the expected increase in the noise level caused by any one of the above modifications must be offset by a compensating change, and an appropriate analysis must be provided.

There are some modifications that this analysis procedure is not intended to be used for. The removal of exhaust mufflers or other changes to an exhaust system typically require some form of testing to determine the acoustical effect, unless the removal of the exhaust system restores the aircraft to an already noise certified configuration. Cutting the tips off an existing propeller blade will tend to increase the blade's thickness with a potential consequential increase in noise level. In both cases a simple back-to-back flight test, conducted according to flight and measurement procedures of Chapter 10 of the Annex, may enable a determination of a no-acoustical change.

5.2.5.3.3 *Parent aircraft*

Before making any no-acoustical change determination, it is necessary to establish the "flight datum" (see 2.2) or "parent" aircraft, the datum design against the extent of any change in noise level is compared.

The "parent" aircraft should be an already approved design, either through an original or supplemental type certificate. The applicant should make clear to the certificating authority to which aircraft models the modification will apply (all engines, propellers, masses, etc.). The applicant should also be aware that the noise level of the parent aeroplane is the proprietary data of the TC or STC holder.
When applying for a no-acoustical change, the applicable certification basis for the changed aircraft will be the same as its parent.

This guidance is limited to the demonstration of a no-acoustical change for aircraft for which the parent aircraft has also been certified against Chapter 10. If the parent aircraft was certified against Chapter 6 or was certified before 1975 (i.e. no Standard applies) the applicant should discuss with the certificating authority all methods to claim for a no-acoustical change.

5.2.5.3.4 *Definitions and equations*

5.2.5.3.4.1 Symbols and definitions

For the purposes of section 5.2.5.3 the following symbols and definitions are used:

c_{HR}	Reference day speed of sound (m/s) at the altitude of the aeroplane based on the temperature at the reference height assuming an ISA temperature lapse rate
D	Diameter of propeller (m)
D_{15}	Sea level, ISA take-off distance (m) to a height of 15 m at the maximum certificated take-off mass and maximum certificated take-off power
H_R	Reference height (m) over the prescribed measurement location
P	Engine power (kW)
M_H	Helical tip Mach number
Best R/C	Best rate of climb (m/s) at the maximum certificated take-off mass and the maximum power and engine speed that can be continuously delivered by the engine(s) during the second phase at sea level (ISA)
N	Propeller rotational speed (rpm)
T_{HR}	Standard day temperature at reference height (ºC)
p_{HR}	Standard day pressure at reference height (hPa)
V_{CAS}	Indicated airspeed (m/s)
V_{IAS}	Calibrated airspeed (m/s)
V_{TAS}	True airspeed (m/s)
V_Y	Best rate of climb speed (m/s)
ϕ	Propeller inflow angle (degrees)

Subscripts

par	Parent
mod	Modified

5.2.5.3.4.2 Relevant equations

For the purposes of the examples shown in 5.2.5.3.5 the following equations are used.

Note.— For the following examples it is assumed that the conversion factor between V_Y in IAS and V_Y in CAS is equal to 1. For specific calculations the conversion should be based on the "position error" data taken from the approved aircraft flight manual.

Equation 1 Reference height:

$$H_R = \left(2\,500 - D_{15}\right)\tan\left[\sin^{-1}\left(\frac{R/C}{V_Y}\right)\right] + 15$$

Equation 2 Temperature at reference height:

$$T_{HR} = 15 - 0.0065 H_R$$

Equation 3 Pressure at reference height:

$$p_{HR} = 1\,013.25 \times \left(1 - 0.0065 \times \frac{H_R}{288.15}\right)^{\frac{-9.80665}{-0.0065 \times 287.05287}}$$

Equation 4 True airspeed at reference height (m/s):

$$V_{TAS} = V_{CAS} \times \sqrt{\frac{\rho}{\rho_{HR}}} = V_{CAS} \times \sqrt{\frac{1.225}{\rho_{HR}}} = V_{CAS} \times \sqrt{\frac{1.225}{(p_{HR} \times 100)/[R \times (T_{HR} + 273.15)]}}$$

$$V_{TAS} = V_{CAS} \times \sqrt{\frac{1.225}{(p_{HR} \times 100)/[287.04 \times (T_{HR} + 273.15)]}}$$

Equation 5 Speed of sound:

$$c = 343.2 \times \sqrt{\frac{T_0 + 273.15}{293.15}}$$

Equation 6 Helical tip Mach number:

$$M_H = \frac{\left[\left(\pi DN/60\right)^2 + {V_{TAS}}^2\right]^{1/2}}{c}$$

5.2.5.3.5 *Examples of type design changes that may affect noise levels*

Typical applications for type design changes that require an evaluation of the effect of the change on noise levels include:

a) Change in take-off mass;

b) Change in propeller diameter;

c) Change in engine power; and

d) Modification that changes the drag without any change in engine or propeller installations. Examples include installation of external cargo containers, larger tyres on fixed gear or advertising light arrays.

In some cases, changes in noise level introduced by these modifications can be determined analytically by using existing data for the parent aeroplane or by supplementing the existing data with additional performance information when that performance is approved by the certificating authority. If the performance of the modified aeroplane is "equal to" or "better" than the parent aircraft (shorter take-off distance, increased rate of climb, etc.) the applicant **cannot** take credit for the "better" performance when evaluating a modification for acoustic change unless the new performance is subsequently published in an approved aircraft flight manual (AFM), aircraft flight manual supplement (AFMS) or supplemental aeroplane flight manual (SAFM) for the modification.

5.2.5.3.5.1 Change in take-off mass

For a change in aeroplane take-off mass without any change in engine/propeller installation, the following factors influence the noise level under the procedures of Chapter 10 of the Annex:

a) The change in performance from the AFM or AFMS; and

b) The change in climb angle at the modified mass and the consequential change in propeller inflow angle might need to be taken into consideration for its potential acoustical effect according to the will of the certificating authority.

An increase in maximum take-off mass will normally generate a lower reference height. An increase in airspeed can also cause a modest change in the reference helical tip Mach number, which may increase the noise level.

The change in noise level can be calculated as per Example 1.

Example 1: Calculate the change in noise level if the mass of an airplane is increased from 1 360 kg to 1 450 kg, without any other changes, given the following (note that all of the data given should be readily available from the AFM or pilot's operating handbook):

Step 1. Take performance data from the approved AFM:

$D_{15,par}$ = 680 m | $D_{15,mod}$ = 770 m

V_{Ypar} = 46.3 m/s | V_{Ymod} = 47.8 m/s

R/C_{par} = 4.9 m/s | R/C_{mod} = 4.5 m/s

D_{par} = 2.13 m | D_{mod} = 2.13 m

N_{par} = 2 600 rpm | N_{mod} = 2 600 rpm

Step 2. Calculate reference height H_R (as per Equation 1):

Parent: $H_{Rpar} = 209$ m

Modified: $H_{Rmod} = 179$ m

Step 3. Calculate reference helical tip Mach number $M_{HR:}$

a) Speed of sound at reference height (as per Equation 5):

Parent: $c_{par} = 339.46$ m/s

Modified: $c_{mod} = 339.57$ m/s

b) Best rate of climb speed (true airspeed at reference height):

Parent: $V_{Ypar} = 46.77$ m/s

Modified: $V_{Ymod} = 48.21$ m/s

c) Helical tip Mach number M_H at reference height (as per Equation 6):

Parent: $M_{par} = 0.86525$

Modified: $M_{mod} = 0.86564$

Step 4. In this example the change in noise level due to the change in engine power can be assumed to be zero since the reference engine power remains essentially constant.

Step 5. Calculate the change in noise level under the reference conditions of Chapter 10 of the Annex for the increase in take-off mass:

a) Change in noise level (Δ_1) due to the decrease in height from 209 m to 179 m (see 5.2.2 b) of Appendix 6 of the Annex for origin of equation):

$$\Delta_1 = 22 \log (H_{Rpar} / H_{Rmod}) = 22 \log (209 / 179) = \underline{+1.48 \text{ dB}}$$

b) Change in noise level, Δ_2, due to the increase in helical tip Mach number (see 5.2.2 c) of Appendix 6 of the Annex for origin of equation):

$$\Delta_2 = 150 \log (M_{mod} / M_{par}) = 150 \log (0.86564 / 0.86525) = \underline{+0.03 \text{ dB}}$$

Note.— A value of 150 for the k-factor in the helical tip Mach number adjustment may only be used when M_{mod} is higher than M_{par}. When M_{mod} is lower than M_{par} only an approved k-factor determined from flight tests of the particular aeroplane/propeller combination may be used.

c) Change in noise level, Δ_ϕ, due to change of inflow angle:

The change in noise level arising from the change in propeller inflow angle may need to be taken into account based on sufficient substantiation and at the discretion of the certificating authority.

In this example the propeller inflow angle of the parent aeroplane, ϕ_{par}, is assumed to be 4.25° and that of the modified aeroplane, ϕ_{mod}, is assumed to be 3.00°. The change in noise level due to the change in inflow angle may be calculated as follows:

$$\Delta_\phi = X\,(\phi_{mod} - \phi_{par}) = 0.5\,(3.00 - 4.25) = \underline{-0.63\text{ dB}}$$

Here the X-factor is assumed to be 0.5. The certificating authority may require that propeller inflow angles ϕ_{par}, ϕ_{mod} and the X-factor be determined from flight tests of the particular aeroplane/propeller combination.

d) Total change in noise level:

The total change in noise level (ΔL) is the algebraic sum of the three calculated changes Δ_1, Δ_2 and Δ_ϕ:

$$\Delta L = 1.48 + 0.03 - 0.63 = \underline{+0.88\text{ dB}}$$

The increase in take-off mass represents a significant acoustical change, and the applicant will be required to develop new noise levels for the modified airplane. It may be that in such a case the certificating authority would require a full Chapter 10 noise test.

5.2.5.3.5.2 Change from fixed pitch to variable pitch propeller

No commonly approved method exists for analytically determining a no-acoustical change in case of replacement of a fixed pitch propeller by a variable pitch propeller. In such cases the certificating authority will likely require that a flight test be performed.

5.2.5.3.5.3 Change in propeller diameter

The effect on the Chapter 10 noise level due to a change in propeller diameter without any change in power or performance can be determined via the following equation:

$$\Delta_2 = k_2 \log\,(M_{mod} / M_{par}) \text{ where:}$$

k_2 equals a constant dependent on the propeller design and Mach number range. A nominal value of 150 is permitted if M_{par} is less than M_{mod}.

Note.— Such a determination is only possible for propellers of similar geometry.

An increase in propeller diameter will of itself increase the noise level at source. In many cases the increase of propeller diameter is associated with a change in performance (N, D_{15}, R/C, V_Y). A change of performance can only be taken into account if it is defined in the AFM or AFMS. The following two examples illustrate the effect that changes in propeller diameter have on the noise level.

Example 2: The aeroplane in Example 1 is normally equipped with a two-bladed propeller of 2.13 m diameter. The same propulsive efficiency is claimed when the propeller is replaced with a two-bladed propeller of 2.18 m diameter, the engine and propeller speed being unchanged. For the same reference height and airspeed, the difference in noise level between the two installations may be calculated as follows:

a) The best rate of climb speed in TAS, V_Y, is assumed to be 46.75 m/s for both the parent and the modified aeroplane;

b) The helical tip Mach number at the reference height is calculated assuming a propeller speed (N) of 2 600 rpm, and the speed of sound (c) for the parent and the modified aeroplane to be 339 m/s:

$$M_{par} = 0.86641$$
$$M_{mod} = 0.88624$$

c) The increase in noise level due to increase in helical tip Mach number is then calculated as follows:

$$\Delta_2 = 150 \log (0.88624 / 0.86641) = 1.47 \text{ dB}$$

The analytical analysis has demonstrated that the change (> 0.1 dB) is an acoustical change.

Example 3: An applicant wishes to replace an existing propeller having a diameter of 1.93 m with a propeller having a diameter of 2.03 m. The new propeller is designed to provide a shorter take-off distance and better rate of climb. The applicant does not want to take credit for the improvement in take-off distance or climb rate.

The applicant has demonstrated to the satisfaction of the certificating authority that when flying according to the Chapter 10 reference climb conditions, the propeller speed for the existing propeller is 2 600 rpm. The applicant has further demonstrated that with the new propeller operating at a reduced speed of 2 500 rpm the take-off and climb performance is unchanged. Assuming that the propeller tip shape and the thickness of the parent and changed propellers are identical, the change in noise level can be determined as follows:

a) The best rate of climb speed in TAS, V_Y is assumed to be 46.75 m/s for the parent and the modified aeroplane;

b) The helical tip Mach number, M_H, at the reference height is calculated as follows, assuming the speed of sound, c, is assumed to be 339 m/s for both the parent and the modified aeroplane:

$$M_{par} = 0.78722$$
$$M_{mod} = 0.79589$$

c) The increase in noise level due to increase in helical tip Mach number is then calculated as follows:

$$\Delta_2 = 150 \log (0.79589 / 0.78722) = 0.71 \text{ dB}$$

Although the propeller speed has been reduced due to the improved performance of the new, increased diameter propeller, a no-acoustical change has not been proven via analytical means.

5.2.5.3.5.4 Change in engine power

Increasing the power output of an engine without changing the take-off mass of an aeroplane will adversely affect the aircraft’s source noise characteristics and, without any change in performance, lead to an increase in the Chapter 10 of the Annex noise level. In general, though an improvement in the performance does take place, take-off distance is shortened and climb rate is increased. If the effect on the increase in source noise is offset by the improved performance, the applicant may be able to demonstrate a no-acoustical change. A demonstration of this sort would only be acceptable if the noise level/power relationship has been established via flight tests. The value for the k-factor of 17 described in 5.2.2 d) of Appendix 6 of the Annex is not acceptable. The value 17 is intended for taking into account small power changes arising from differences between ambient test conditions and reference conditions. The following example illustrates the required analysis.

Step 1. Take performance data from the approved AFM:

D_{15par} = 680 m	D_{15mod} = 609 m
V_{Ypar} = 46.3 m/s	V_{Ymod} = 46.3 m/s
R/C_{par} = 4.9 m/s	R/C_{mod} = 6.08 m/s
D_{par} = 2.13 m	D_{mod} = 2.13 m
N_{par} = 2 600 rpm	N_{mod} = 2 600 rpm
P_{par} = 168 kW	P_{mod} = 186 kW

Step 2. Calculate reference height H_R (as per Equation 1):

Parent: H_{Rpar} = 209 m

Modified: H_{Rmod} = 265 m

Step 3. Calculate the reference helical tip Mach number (note that in this case the helical tip Mach number is influenced only by the change in the speed of sound due to the change in reference height):

a) Speed of sound at reference height (as per Equation 5):

Parent: c_{par} = 339.46 m/s

Modified: c_{mod} = 339.24 m/s

b) Best rate of climb speed (true airspeed at reference height):

Parent: V_{Ypar} = 46.77 m/s

Modified: V_{Ymod} = 46.89 m/s

c) Helical tip Mach number M_H at reference height (as per Equation 6):

Parent: M_{par} = 0.86525

Modified: M_{mod} = 0.86587

Step 4. Calculate the change in noise level:

a) Change in noise level (ΔH) due to the increase in height from 209 m to 265 m (see 5.2.2 b) of Appendix 6 of the Annex for origin of equation):

$$\Delta H = 22 \log (H_{R,par}/H_{R,mod}) = 22 \log (209/265) = -2.30 \text{ dB}$$

b) Change in noise level, Δ_2, due to the increase in helical tip Mach number (see 5.2.2 c) of Appendix 6 of the Annex for origin of equation):

$$\Delta_2 = 150 \log (M_{mod}/M_{par}) = 150 \log (0.86587/0.86525) = +0.05 \text{ dB}$$

c) Change in noise level, Δ_3, due to increase in engine power (for this example it is assumed that a k-factor of 20 has been established via flight tests):

$$\Delta_3 = 20 \log (PR_{mod}/PR_{par}) = 20 \log (186/168) = +0.88 \text{ dB}$$

d) Change in noise level, Δ_ϕ, due to change of inflow angle:

The change in noise level arising from the change in propeller inflow angle may need to be taken into account based on sufficient substantiation and at the discretion of the certificating authority.

In this example the propeller inflow angle of the parent aeroplane (α_{Par}) is assumed to be 3.11° and that of the modified aeroplane (α_{Mod}) is assumed to be 4.25°. The change in noise level due to the change in inflow angle may be calculated as follows:

$$\Delta_\phi = X (\phi_{mod} - \phi_{par}) = 0.5 (4.25 - 3.11) = +\underline{0.57 \text{ dB}}$$

Here the X-factor is assumed to be 0.5. The certificating authority may require that propeller inflow angles α_{Par}, α_{Mod} and the X-factor are determined from flight tests of the particular aeroplane/propeller combination.

e) Total change in noise level:

The total change in noise level (ΔL) is the algebraic sum of the three calculated changes Δ_1, Δ_2, Δ_3 and Δ_ϕ:

$$\Delta L = -2.30 + 0.05 + 0.88 + 0.57 = \underline{-0.80 \text{ dB}}$$

In this example the change in noise level due to the increase in engine power is offset by the higher reference height arising from the improvement in take-off performance. A no-acoustical change has been demonstrated, and the noise level of the modified aircraft will be the same as that of the parent aeroplane.

5.2.5.3.5.5 Increase in drag with no other changes

A modification to an aeroplane that increases its drag will adversely affect the take-off and/or climb performance and will therefore lead to an increase in the aircraft's noise level. If either the flight manual approved take-off distance is increased or the rate of climb decreased, the reference flyover height will be lowered. The change in noise level and hence the determination of an acoustical change may be calculated from the adjustment equations provided previously.

5.2.5.3.5.6 Acoustical effect of combined changes

On occasions an aeroplane modification will involve the simultaneous embodiment of several individual changes. Examples of such composite changes include replacing an engine and fixed pitch propeller with an engine with higher power and a variable pitch propeller or increasing the engine power and at the same time the take-off mass. It can often be quite complicated to determine the overall acoustic impact of these composite changes. In such cases the use of an analytical determination based on the combined effect of calculation methods similar to those described above should be discussed with the certificating authority. It may be that additional substantiation or flight tests will be required.

5.3 TECHNICAL PROCEDURES INFORMATION

5.3.1 Worked example of calculation of reference flyover height and reference conditions for source noise adjustments (Chapter 10)

5.3.1.1 *Introduction*

The reference flyover height for an aeroplane certificated to Chapter 10 of the Annex is defined at a point that is 2 500 m (8 202 ft) from the start-of-roll beneath a reference flight path determined according to the take-off reference procedure described in 10.5.2 of Chapter 10 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 section. The relationship between the reference height and the conditions to which source noise corrections are to be made is also explained.

5.3.1.2 *Take-off reference procedure*

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

a) the first phase commences at "brakes release" and continues to the point where the aircraft reaches 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 (50 ft) below is often referred to as "reference zero"; and

b) 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.— 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.

5.3.1.3 *Expression for reference height*

The reference flyover height is defined according to the take-off reference flight path at a point 2 500 m (8 202 ft) from the start-of-roll for an aeroplane taking off from a paved, level runway under the following conditions:

a) sea level atmospheric pressure of 1 013.25 hPa;

b) ambient air temperature of 15°C (i.e. ISA);

c) relative humidity of 70 per cent; and

d) 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:

$$H_R = \left(2\,500 - D_{15}\right) \times \tan\left[\sin^{-1}\left(\frac{\text{Best R/C}}{V_Y}\right)\right] + 15\,,$$

where:

— 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;

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

— V_Y is the speed (m/s) for the best rate of climb.

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

$$H_R = (8\,203 - D_{50}) \times \tan\left[\sin^{-1}\left(\frac{\text{Best R/C}}{101.4\,V_Y}\right)\right] + 50\ ,$$

where:

— D_{50} is the sea level, ISA take-off distance in feet to a height of 50 ft at the maximum certificated take-off mass and maximum certificated take-off power;

— Best R/C is the sea level, ISA best rate of climb (ft/s) at the maximum certificated take-off mass and the maximum power and engine speed that can be continuously delivered by the engine(s) during this second phase; and

— V_Y is the speed (kt) for the best rate of climb.

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

In addition, the best rate of climb speed, V_Y, used in the equation for H is defined as the true airspeed (TAS). However in the flight manual, speed is normally presented in terms of 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.

5.3.1.4 ***Reference conditions for source noise adjustments***

Paragraphs 5.2.1 c) and 5.2.1 d) of Appendix 6 of the Annex 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 the reference height, H_R, is calculated under ISA conditions (i.e. for an ambient sea level temperature of 15°C and assuming a standard temperature lapse rate of 1.98°C per 1 000 ft). The reference temperature, T_R°C, can be defined as:

$$T_{HR} = 15 - 1.98\left(\frac{H_R}{1\,000}\right).$$

The reference atmospheric pressure, p_{HR} in hPa, is similarly calculated at the reference height (H_R) for a standard sea level pressure of 1 013.25 hPa, assuming a standard pressure lapse rate such that:

$$p_{HR} = 1\,013.25\left[1 - \left(6.7862 \times 10^{-6}\, H_R\right)\right]^{\frac{-9.80665}{-.0065 \times 287.05287}}.$$

5.3.1.5 ***Worked example for the calculation of reference flyover height and the associated reference atmospheric conditions***

5.3.1.5.1 *For reference flyover height calculation*

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

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

The climb speed associated with the R/C figures is given as 80 knots indicated airspeed (KIAS). The corresponding true airspeed at the reference conditions cited in Chapter 10 of the Annex is equal to the IAS, corrected according to the airspeed calibration table at the appropriate flap setting of 0°. Thus V_Y is 81 knots true airspeed (KTAS).

Entering these parameters into the equation for reference height expressed in feet (H_R ft) given in 5.3.1.3 gives:

$$\mathbf{H_R = \left(8\,203 + 1\,370\right) \times \tan\left[\sin^{-1}\left(1000 / (101.4 \times 81)\right)\right] + 50},$$

and so H_R = 888 ft.

5.3.1.5.2 *For calculation of reference atmospheric conditions*

a) The reference temperature at the reference height, H_R, is given by the equation for T_R in 5.3.1.4:

$$T_{HR} = 15 - 1.98\left(\frac{888}{1\,000}\right),$$

and so T_{HR} = 13.24°C.

b) The reference pressure at the reference height is given by the equation for p_{HR} in 5.3.1.4:

$$p_{HR} = 1\,013.25\left[1-\left(6.7862\times10^{-6}\times888\right)\right]^{\frac{-9.80665}{-0.0054\times287.05287}}$$

and so p_{HR} = 981 hPa.

Table 5-1. Example of flight manual performance section

SECTION 5. PERFORMANCE

1. INTRODUCTION

The data processed in this section enable 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 assume average pilot skill and an aircraft engine and propeller in good condition.

No additional factors are included, and it is the pilot’s responsibility to apply safety factors that must not be less than those …

6. AIRSPEED CALIBRATION

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

TAKE-OFF DISTANCE PAVED RUNWAY (1) — CONDITIONS

Flaps — 15°
Mass — 1 920 lb
Power — Full throttle

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

Airfield height (ft)	ISA – 20°C		ISA – 10°C		ISA		ISA + 10°C		ISA + 20°C		ISA + 30°C	
	Ground roll	Total to 50 ft	Ground roll	Total to 50 ft	Ground roll	Total to 50 ft	Ground roll	Total to 50 ft	Ground roll	Total to 50 ft	Ground roll	Total to 50 ft
Sea level	530	1 230	565	1 290	600	1 370	700	1 580	750	1 715	840	1 900
5 000	1 045	2 835	1 065	2 435	1 090	2 580	1 170	2 670	1 295	2 840	1 290	2 905
10 000	1 0465	3 335	1 490	3 390	1 510	3 435	1 575	3 560	1 610	3 695	1 670	3 790

RATE OF CLIMB — CONDITIONS

Flaps up
Mass — 1 920 lb

Full throttle
Speed — 80 KIAS

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

KIAS = knots indicated airspeed
KCAS = knots calibrated airspeed

Chapter 6
GUIDELINES FOR HELICOPTERS NOT EXCEEDING 3 175 KG EVALUATED UNDER APPENDIX 4 OF ANNEX 16, VOLUME I

6.1 EXPLANATORY INFORMATION

6.1.1 General

Helicopters not exceeding 3 175 kg (7 000 lb) can be certificated under either Chapters 8 or 11 of the Annex. Helicopters exceeding 3 175 kg (7 000 lb) can be certificated only under Chapter 8 of the Annex. Guidelines for helicopters certificated using Chapter 8 of the Annex are provided in Chapter 4 of this manual.

Unlike Chapter 8 of the Annex that requires take-off, overflight and approach tests with noise measurements being made at three measuring points, compliance with Chapter 11 of the Annex is based on overflight tests only, with the noise data being obtained only at one microphone located under the flight track. Flight path adjustments are simplified and the final results determined in terms of SEL instead of EPNL.

Also since the Chapter 11, Annex 16, procedure is based on overflight tests only, there are no trade-off provisions between flight conditions as allowed in Chapter 8 of the Annex. However, if a helicopter not exceeding 3 175 kg (7 000 lb) fails to comply with the noise limit of Chapter 11 of the Annex, certification of the helicopter under the Chapter 8, Annex 16, procedures is allowed.

6.1.2 Noise measurements

See 3.1 for technical procedures generally applicable for noise certification tests of all aircraft types including those evaluated under the provisions of Appendix 4 of the Annex. In the following section procedures specific to Appendix 4 are presented.

6.1.3 Noise certification test and measurement conditions

AMC No. 2 A4 2.2.2
[Atmospheric test conditions]

1) *Temperature/relative humidity test window*

Tests are permitted over the range of temperature and relative humidity specified in 2.2.2 b) of Appendix 4 of the Annex and shown in Figure 6-1.

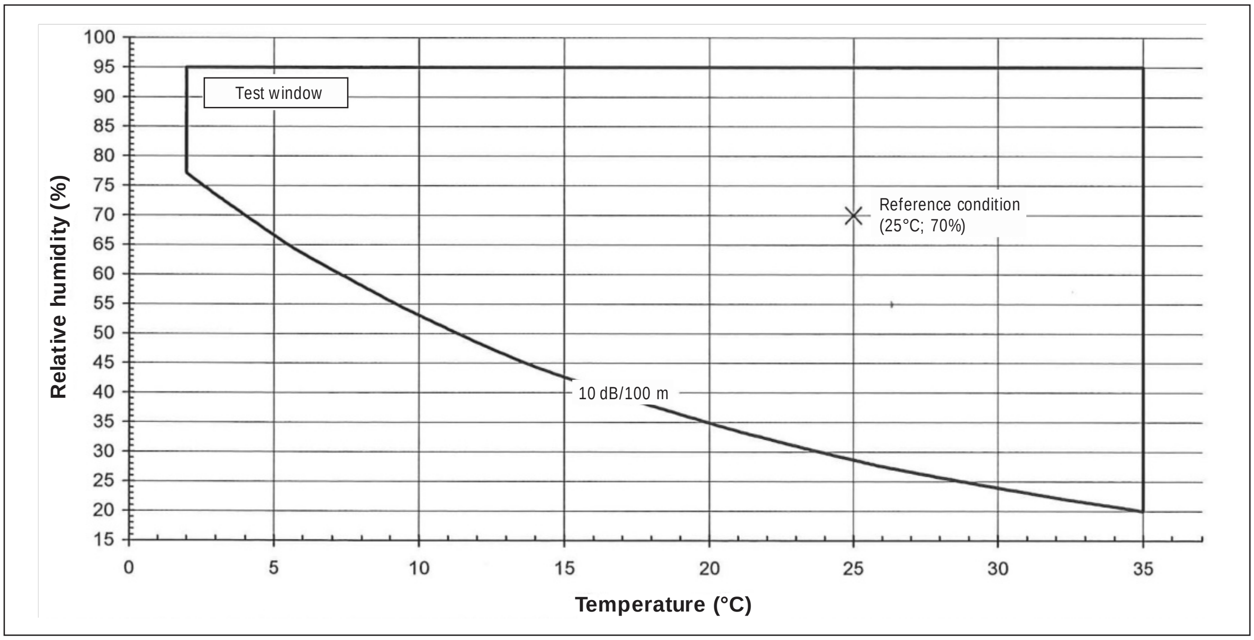


Figure 6-1. Appendix 4 temperature/relative humidity test window

2) *Testing outside the temperature and relative humidity window*

If the limits of 2.2.2 b) of Appendix 4 of the Annex cannot be met, but the tests can be conducted within the temperature/relative humidity limits specified in 2.2.2.4.1 b) of Appendix 2 of the Annex, then the applicant may alternatively elect to use the equivalent procedure defined in 6.2.2.2.

3) *Meteorological measurements*

Measurements of the meteorological conditions are required to be made using equipment approved by the certificating authority. The temperature, relative humidity and wind measurements are required to be made in the vicinity of the noise measurement point at a height between 1.2 m (4 ft) and 10 m (33 ft). This allows the use of hand-held equipment but does not preclude the use of more complex measuring systems. Temperature and relative humidity may be measured by a hand-held psychrometer. This device measures the wet and dry bulb temperatures from which the relative humidity is obtained. Similarly wind measurements may be made using a hand-held device if its specifications comply with the provisions of 2.2.2.1 of Appendix 2 of the Annex.

4) *Temperature and relative humidity*

Measurements of temperature and relative humidity should be made at intervals of not more than one hour to ensure that the test conditions remain in the required limits. It is advisable to make measurements for each flight in case it is required at a later time to verify the test conditions.

Section 6.2.2.2 provides an equivalent procedure to the specifications for temperature and humidity measurement given in 2.2.2 b) of Appendix 4 of the Annex.

AMC No. 3 A4 2.2.2
[Anomalous meteorological conditions]

1) *OAT differential*

The presence of anomalous meteorological conditions can be reasonably determined by monitoring the outside air temperature (OAT) using the helicopter on-board temperature gauge. Anomalous conditions that could impact the measured levels can be expected to exist when the OAT at 150 m (492 ft) is higher than the temperature measured at a height between 1.2 m (4 ft) and 10 m (33 ft) above the ground by more than 2°C (3.6°F). This check should be made in level flight at a height of 150 m (492 ft) within 30 minutes of each noise measurement.

AMC No. 4 A4 2.2.2
[Wind speed]

1) *Wind speed limitations*

Wind speed measurement points and limits are given in 2.2.2 c) of Appendix 4 of the Annex. Wind speed measurement system specifications are given in 2.2.2.1 of Appendix 2 of the Annex. Measurements should be taken frequently and, if near the limit, at least prior to each flight to confirm that the requirements are met. Particular attention should be given to the crosswind component since this can often be the limiting factor during testing. If feasible, the reference flight path direction can be changed to reduce the impact of this requirement. These wind speeds should be recorded and included in the report of the noise certification programme. Wind limits are intended to minimize the adverse effects of wind on helicopter noise generation and sound propagation.

AMC No. 5 A4 2.2.2
[Anomalous wind conditions]

1) *Identification of anomalous winds*

Anomalous winds are difficult to quantify but, providing the helicopter can be easily flown within the flight path and airspeed limits defined in the Annex, there is no excessive side slip or yawing of the helicopter and no indication of rough air, then the flights can be considered acceptable. In the case where wind effects are anticipated to be a likely problem, an agreement between the applicant and the certificating authority or designated observer should be reached prior to testing to determine the acceptability criteria. Normally such issues arise only with gusty wind conditions near the 5.1 m/s (10 kt) wind speed limit, high crosswind conditions or the presence of strong thermals.

GM A4 2.4
[Flight test conditions]

1) *Overflight height*

A reference overflight height of 150 ± 15 m (492 ± 50 ft) above the ground at the noise measurement point is specified as indicated in Figure 6-2. The measured noise data must be adjusted for the effects of spherical spreading between the helicopter test flight path and the reference flight path, and between reference airspeed and adjusted reference airspeed as specified in 5.2.2 of Appendix 4 of the Annex.

2) *Flight path measurement*

The helicopter flight path is also required to be within ±10° of the vertical above the noise measurement point (see Figure 6-2). This requirement, along with the height test window, means that the helicopter has to fly through a height/off-track test window located directly above the noise measurement point. There is no requirement to determine the magnitude of the off-track distance, but it is necessary to show that the helicopter is within the required height and angular limits. The applicant may therefore find merit in recording the off-track values for subsequent confirmation of compliance.

3) *Flight track: markings*

The helicopter has to fly on a straight path and be within ±10° of the vertical overhead the noise measurement point as shown in Figure 6-2. In order for this to be successfully accomplished the applicant should consider marking on the ground, in a manner that can be readily seen from the helicopter, the intended track and associated lateral limits. Brightly coloured or day-glow markers or lights to mark the flight track are advisable. These markings will be very important in the case of a small helicopter where the on-board equipment may be the minimum required to comply with the airworthiness certification.

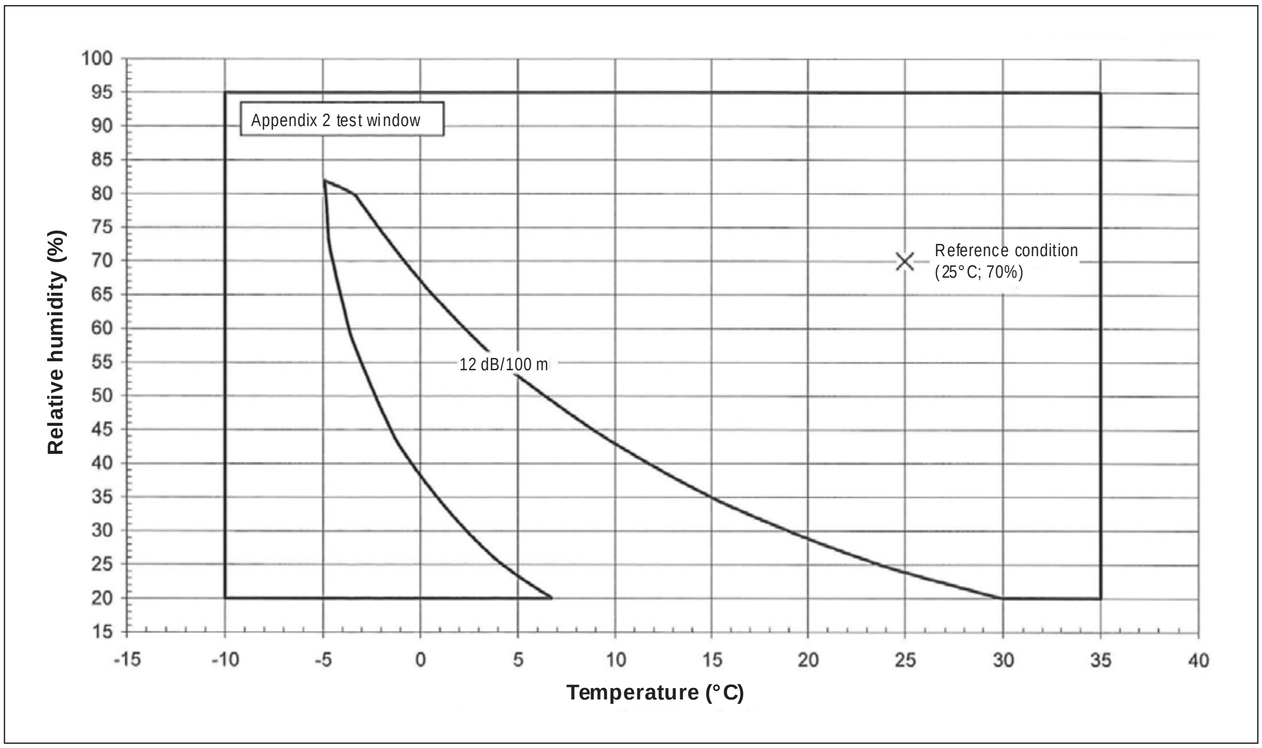


Figure 6-2. Flight boundaries for overflight test condition

4) *Number of test runs*

A minimum of six overflights, with an equal number of flights with headwind and tailwind components over the noise measurement point, are required. These test runs should be conducted in pairs, since the aim is to minimize the influence of wind speed and direction on the measured SEL. The tests in each pair should be conducted immediately one after another in order that the meteorological conditions are as similar as possible for the two test runs. It should be possible to determine immediately after each test run if it meets the necessary requirements and thus relatively easy to establish when three pairs of valid test runs have been made. The applicant would also be advised to conduct one or two additional pairs of test runs to ensure that after all the test parameters have been examined a minimum of three valid pairs of test run results are available. If additional valid pair(s) of test runs are obtained these will be required to be included in the analysis to determine the arithmetic average SEL.

5) *Landing gear position*

If the helicopter has a retractable landing gear, the landing gear position for noise tests needs to be that used for the cruise configuration.

AMC A4 2.4
[Flight test conditions]

1) *Test period*

The test conditions have to be maintained, or held constant, over an adequate distance (time interval) to encompass the 10 dB-down period. The maximum A-weighted sound pressure level, dB(A) or L_{ASmax}, will normally occur when the helicopter is at, or just prior to, the position directly above the noise measuring point. Pre-test flights should be conducted to determine the 10-down period and ensure this period is adequately captured by the noise measurement system. It is advisable that the helicopter flight test conditions are stabilized well in advance of the initial 10 dB-down point and maintained until well after the second 10 dB-down point to ensure a valid noise measurement is obtained.

2) *Maximum normal operating rotor speed*

In order that the noise levels are representative of normal operation, the rotor speed used must be the maximum normal value associated with flyover at the reference conditions. Also, since on most helicopters small changes in rotor speed occur during a stabilized flight, a ±1 per cent rpm variation is allowed.

3) *Test mass*

Fuel, together with the mass of the pilot, flight observers and ballast, are normally used to set the mass of the test helicopter within the required test range of +5 per cent/–10 per cent of the maximum take-off mass. Fuel burn (i.e. decrease in fuel mass) should be documented to determine the actual test value. Care must be taken regarding the location of ballast to ensure it does not have any adverse impact on the applicable centre of gravity limits.

Unlike in Chapter 8, there is no requirement to conduct any test run above the maximum take-off mass. Note that variation of the overflight noise levels within the allowable mass limits is small and for this reason no adjustments for difference in test masses are required. The helicopter mass, or the quantity of fuel from which the mass of the helicopter can be calculated, should be recorded for each flight.

Note.— Conducting the tests as near as possible to the upper mass limit of +5 per cent can also be useful in supporting noise certification of future increases in maximum gross mass of the helicopter by minimizing the likelihood of having to conduct new tests.

4) *Background noise*

Some initial pre-test overflights should be performed to confirm helicopter noise levels exceed background noise by 15 dB(A) as specified in 4.4.4 of Appendix 4 of the Annex. Certificating authorities have generally accepted that the requirement has been met if the maximum helicopter noise level exceeds background noise levels by 15 dB(A). If this requirement cannot be met when the overflight test is conducted at 150 m (492 ft), a lower overflight height approved by the certificating authority may be used. This normally will be required only in the case of lightweight/small helicopters or those that generate extremely low noise levels.

Variations in measured noise levels of up to ±1.5 dB(A) from flight to flight may typically occur. The applicant should therefore ensure that the difference between background noise and helicopter noise levels is adequate for the quietest overflight noise measurements anticipated. Such information may also be useful for adjusting the sensitivity of the noise measurement system. The level of background noise may be influenced by the location of the test site.

GM A4 2.4.2
[Flight test conditions]

1) *Adjusted reference airspeed*

The overflight adjusted reference airspeed, V_{ar} V_{AR}, is defined as the value at the test temperature that gives the same advancing main rotor blade tip Mach number (M_{AT}) as associated with the reference temperature of 25°C (77ºF). On most helicopters the controlling noise source is dependent on the advancing blade tip Mach number. The advancing blade tip Mach number is dependent on the temperature and thus the sound level varies with temperature. To avoid the need to make a source noise correction, as would be required for the overflight tests under Appendix 2 of the Annex unless an equivalent procedure is used, tests to meet the requirements of Appendix 4 of the Annex are required to be conducted at an adjusted reference airspeed, V_{AR}, which gives the same advancing blade tip Mach number at the time of the test as would occur if the test were conducted under the reference conditions. The speed of sound increases with absolute temperature so that tests conducted in temperatures below the reference value of 25°C (77ºF) at the reference overflight height will result in a higher advancing blade tip Mach number, and a reduction in test airspeed will be required to obtain the reference advancing blade tip Mach number. Similarly when the air temperature at overflight reference height is higher than 25°C (77ºF), the overflight test speed must be increased. This requires knowledge of the OAT measured on-board the aircraft at the time of the test. The applicant should note that it is essential to test at the required airspeed value since there is no provision for the adjustment of data obtained at the wrong Mach number.

AMC No. 1 A4 2.4.2
[Flight test conditions]

1) *Test speed for light helicopters*

For the purposes of compliance with Chapter 11 of the Annex, the helicopter should be flown at the test speed, V_{ar} V_{AR}, that will produce the same advancing blade Mach number, M_{ATR}, as the reference speed at reference conditions given in 11.5.1.4 and 11.5.2.1 b) of Chapter 11 of the Annex.

The reference advancing blade Mach number, M_{ATR}, is defined as the ratio of the arithmetic sum of the reference main rotor blade tip rotational speed, V_{tipR}, and the reference helicopter true airspeed, V_R, divided by the speed of sound, c_R, at 25°C (346.1 m/s) such that:

$$M_{ATR} = \frac{V_R + V_{tipR}}{c_R}\ .$$

.

The target test airspeed,V_{AR}, is calculated from:

$$V_{AR} = c\left(\frac{V_R + V_{tip}}{c_R}\right) - V_{tip}\,,$$

where c is the speed of sound obtained from the on-board measurements of outside air temperature.

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

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

will need to be applied. Δ_2 is the increment in decibels that must be added to the measured SEL.

There are two additional requirements for light helicopter test speed. First, the airspeed during the 10 dB-down period should be close (i.e. within ±5.5 km/h (±3 kt)) to the adjusted reference speed (see 11.6.7 of Chapter 11 and 2.4.2 of Appendix 4 of the Annex).

The second speed requirement states that the level overflights shall be made in equal numbers with a headwind component and tailwind component (see 11.6.4 of Chapter 11 of the Annex). For practical reasons, if the absolute wind speed component in the direction of flight, as measured at a height between 1.2 m (4 ft) and 10 m (33 ft) above ground (see 2.2.2 c) of Appendix 4 of the Annex), is less than 2.6 m/s (5 kt), then the effect of wind can be considered to be negligible. In this case, the measured overflight may be used to satisfy a test run in either the headwind or tailwind direction if the overflights are conducted in pairs. Each pair should consist of two overflights performed one after the other in opposite directions over the reference flight track.

Any changes in rotor speed, which may occur with the flight airspeed, will also need to be taken into account in the above calculations to determine the adjusted reference airspeed. If this is likely to occur then this topic should be reviewed with the certificating authority to determine if any additional adjustments to the flight test speed are required. Normally this is not a concern, since the rotor speed will be independent of flight speed.

The applicant should also note that the calculated adjusted reference airspeed, V_{AR}, is the adjusted true airspeed (TAS). Additional information will be required to determine the IAS for use by the pilot. This will normally be based on calibration charts or adjustments for the airspeed measurement system showing the IAS/TAS relationship.

AMC No. 2 A4 2.4.2
[Flight test conditions]

1) *Rotor speed*

The rotor speed can be varied on some helicopters, and on others variations in the rotor speed can occur with flight speed. In order that the noise levels are representative of normal operation, the rotor speed used must be the maximum normal value associated with overflight at the reference conditions.

Note.— It is not the intent to require noise measurements at any value but the maximum used during normal operations, and thus testing at the maximum tolerance rotor speed is not required.

On some helicopters two distinct rotor speed values are available. If both can be used for normal operations then the noise certification has to be conducted at the higher rotor speed. If the higher of the two speeds is restricted to special operations, or if the helicopter is configured so that it cannot be used at the reference conditions and/or during lower altitude flight, then, subject to approval by the certificating authority, testing at the lower rotor speed may be allowed.

On some helicopters it may be possible for the rotor speed to be changed by pilot action. In these cases noise certification will require the highest rotor speed specified in the RFM for the overflight flight condition at the maximum take-off mass to be used.

For most turbine-engine-powered helicopters the rotor speed is automatically linked by the engine control/ governor system to the flight condition. If this results in a different rotor speed at the adjusted reference airspeed to that associated with the reference airspeed, then additional adjustments may be required to ensure the correct advancing blade tip Mach number is used for the tests. If this situation is likely to occur, certificating authority approval of the rotor speed and/or adjusted reference airspeed to be used should be obtained.

On some recently designed helicopters the use of lower rotor speeds has been certificated for operations at low altitudes and/or in cruise flight. Since these lower rotor speeds are defined in the RFM and, if higher rotor speed values cannot be used at the reference conditions, except possibly in an emergency, noise certification is conducted at the certificated lower rotor speed, subject to approval by the certificating authority. If, however, the helicopter simply incorporates a two-speed or multi-speed system, and either can be selected by the pilot, then the highest value is required to be used for noise certification.

6.1.4 Noise unit definition

GM 3.1
[Units]

The noise levels are to be determined in terms of the SEL metric. The SEL is the time-integrated A-weighted sound level over the 10 dB-down period. This metric takes into account both the duration and the level of the sound.

6.1.5 Measurement of helicopter noise received on the ground

AMC A4 4.3
[Noise measurement system]

1) *System and calibration requirements*

The noise measurement system and system calibration requirements are specified in 4.1 through 4.3 of Appendix 4 of the Annex for compliance with Chapter 11 of the Annex. The noise demonstration compliance test plan must include a description of the system to be used for the noise measurement. The certificating authority must approve the measurement system and calibration procedures in order to ensure that accurate measurements and results are obtained.

AMC A4 4.4
[Noise measurement procedures]

1) *Sound level integration period*

The A-weighted sound pressure level must be integrated over the 10 dB-down period. When using an integrating sound level meter where the start and stop times are selected manually, the actual test integration period should be slightly longer than the true 10 dB-down period. This will not have any significant impact on the SEL value, providing the integration period is only a few seconds longer, since the noise levels will be more than 10 dB(A) below the maximum sound level value.

6.1.6 Adjustment of test results

AMC A4 5.0
[Data adjustments]

1) *Height adjustment*

In order to account for the differences between the test heights (H) and reference height of 150 m (492 ft), which influence both the spherical spreading of the noise and the duration of the 10 dB-down period, the Δ_1 adjustment is applied.

2) *Airspeed adjustment*

In order to account for the differences between the adjusted reference airspeed, V_{AR}, and reference airspeed, V_R, which influence the duration of the 10 dB-down period, the Δ_2 adjustment is applied. Variations in the ground speed, and hence duration, as a result of wind at the test height also occur, but since test runs are to be made with equal numbers with headwinds and tailwinds (see 11.6.4 of Chapter 11 of the Annex), this effectively cancels out this effect and no additional adjustments for duration are required.

6.1.7 Reporting of data to the certificating authority

AMC A4 6.0
[Data reporting]

1) *Reporting requirements*

Noise certification data reporting requirements are detailed in section 6 of Appendix 4 of the Annex. Compliance with stabilized test conditions, including test airspeed, average rotor speed and overflight height, should be reported for the 10 dB-down period. If an acoustic data recording is made, information about the recorder, including frequency bandwidth and sample rate and operating mode, should be recorded.

2) *Lateral position flight track data*

There is no requirement to determine the lateral off-track position directly above the noise measurement point, since it is necessary to show only that it is within the requirements defined in 11.6.8 of Chapter 11 of the Annex. Even so, an applicant may find merit in determining and reporting the lateral off-track distance, with the height information that is required, as a way to show compliance.

6.2 EQUIVALENT PROCEDURES INFORMATION

6.2.1 General

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. In addition, the Annex establishes a range of test conditions and procedures for adjusting measured data to reference conditions.

6.2.2 Procedures for the determination of changes in noise levels

Changes in noise levels determined by comparison of flight test data for different helicopter model series have been used to establish certification noise levels of modified or newly derived versions by reference to the noise levels of the baseline or "flight datum" helicopter model. These noise changes are added to or subtracted from the noise levels obtained from individual flights of the "flight datum" helicopter model. The confidence intervals of the new data are statistically combined with the "flight datum" data to develop overall confidence intervals (see 3.5).

6.2.2.1 ***Modifications or upgrades involving aerodynamic drag changes***

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

a) for helicopters to be certificated under Chapter 11 of the Annex, 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, an overflight test is performed by using the appropriate noise certification reference and test procedures;

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

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

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

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

With the approval by the certificating authority, it may be possible to conduct testing of light helicopters in compliance with the temperature and relative humidity test limits specified in 2.2.2.2 b) and 2.2.2.2 c) of Appendix 2 of the Annex (see Figure 6-3) instead of the limits specified in 2.2.2 b) of Appendix 4 of the Annex. Temperature and relative humidity measurements shall be made between 1.2 m (4 ft) and 10 m (33 ft) above ground as specified in 2.2.2 b) of Appendix 4 of the Annex and within 30 minutes of each noise measurement as required by 2.2.2.2.1 of Appendix 2 of the Annex. 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 adjusted from the test values of temperature and relative humidity to the reference conditions defined in 11.5.1.4 of Chapter 11 of the Annex. The adjustment procedure shall be similar to that defined in 8.3.2.1 of Appendix 2 of the Annex with the sound propagation distances QK and Q_rK_r, respectively, replaced by H, the height of the test helicopter when it passes over the noise measurement point, and the reference height, 150 m (492 ft).

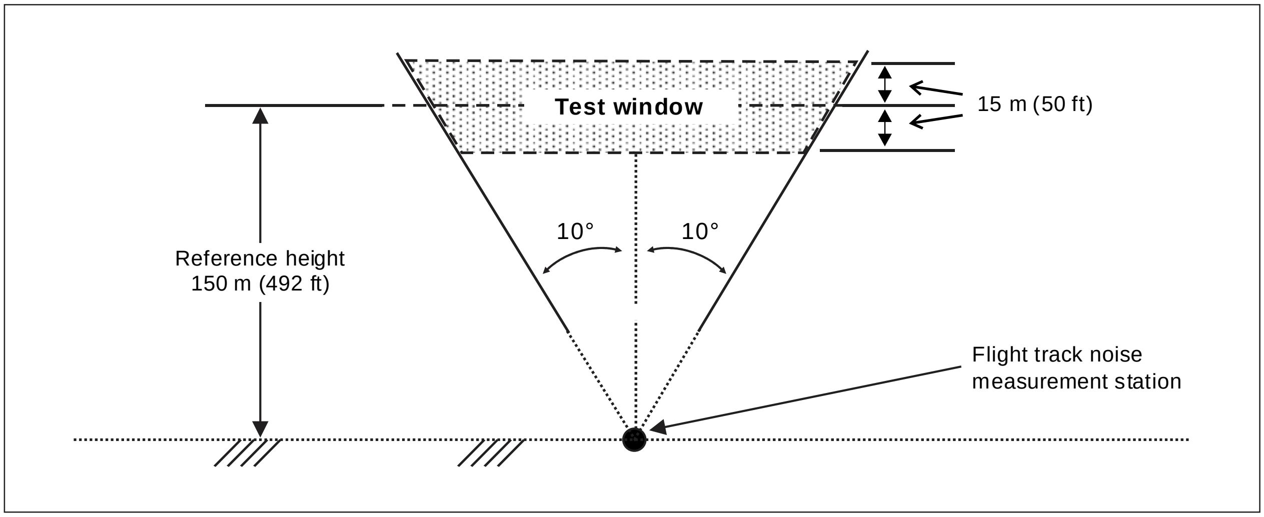


Figure 6-3. Optional Appendix 2 temperature/relative humidity test window

Chapter 7

GUIDELINES FOR TILT-ROTORS EVALUATED IN ACCORDANCE WITH CHAPTER 13 OF ANNEX 16, VOLUME I

7.1 EXPLANATORY INFORMATION

7.1.1 Background

GM No. 1 13.1
[Applicability]

(1) *Intent of the Standards of Annex 16, Volume 1, Chapter 13*

The Standards for the noise certification of tilt-rotors presented in Chapter 13 to the Annex were developed by the CAEP Tilt-Rotor Task Group for the noise certification of a tilt-rotor. The explanatory material in this chapter is intended to give an insight as to how the guidelines were developed.

Note. — A tilt-rotor has the ability to operate at any nacelle angle between 0° and 90°. Chapter 13 of the Annex was developed with the assumption that only a limited number of nacelle angles will be certificated for airworthiness. For an applicant that is seeking civil noise certification of a tilt-rotor that does not have restrictions on the nacelle angles approved for flight, such as those developed for military applications, the nacelle angles selected for the noise certification test should be angles that meet the intent of Chapter 13 of the Annex as discussed in this chapter and are approved by the certificating authority.

(2) *Scope of Chapter 13 Standards*

Chapter 13 of the Annex was modelled after the Standards of Chapter 8 of the Annex and the differences between Chapter 13 and Chapter 8 were intended to be minimal since the character of the noise of this aircraft are much like that of a helicopter.

a) The noise from tilt-rotors will typically be most prominent during departure and approach. In these situations tilt-rotors will normally operate in or near the "helicopter mode".

b) In horizontal overflight, the "helicopter mode" will normally be the noisiest configuration.

c) Chapter 13 of the Annex is confined to tilt-rotors that can take off vertically, excluding those powered-lift aircraft with only STOL characteristics. Tilt-rotors can operate much like normal helicopters, with relatively steep take-off and approach paths, and can maintain sustained cruise flight in "helicopter mode".

d) The type of available noise abatement technology for tilt-rotors is considered to be the similar to helicopters.

(3) *Applicability to Attachment F Guidelines*

The guidelines contain in Attachment F of the Annex are substantially equivalent to the Standard contained in Chapter 13 of the Annex, and the guidance provided in this chapter is therefore applicable to Attachment F.

(4) *Transition phase noise-test point evaluation*

In developing the guidelines of Attachment F as a precursor to the adoption of Chapter 13, one item of strong interest was the transition from one nacelle angle to the other, which might be associated with particular noise-generation mechanisms. For example, when one considers the tilt-rotor transition from aeroplane mode to helicopter mode while decelerating, there is a phase in which the component of the speed vector that is perpendicular to the rotor changes from “top to bottom” to “bottom to top”. It would be conceivable that sometime during the transition phase, blade vortices would be ingested or another non-stationary effect would create additional noise.

A number of overflights of the Bell XV-15 were listened to, one of which was especially set up to study the noise during transition. In this run, the tilt-rotor (Bell XV-15) passed overhead at 150 m (492 ft) while transitioning from aeroplane to helicopter mode. No special phenomena were heard during this flight. In addition, during the other runs, in which there were demonstrations of hover, hover turns, sideward flight, take-off, level overflights at various speed/nacelle angle combinations, and approaches at 6° and 9°, no particularities were heard other than normal BVI noise during both the 6° and 9° approaches. During the procedures to set the aircraft up for the various runs, several transitions were made from helicopter to aeroplane mode and back, which were listened to from different positions relative to the aircraft. No particular noise was heard.

Based on this experience and the arguments stated as follows, it was decided not to attempt to define a special test point aimed at catching transition noise of tilt-rotors.

The arguments for this were:

a) Experienced observers from industry claimed they have never noticed any particular noise phenomena associated with the transitional phase. This was backed up by the specific observations of the Bell XV-15 referred to above.

b) The conversion rate is relatively slow, which means that during the whole conversion process, the flow field also changes very slowly.

c) If there were to be a transitional noise, it would probably be related to some form of BVI. This phenomenon is covered under the approach procedure, and it might be hard to justify adding a measurement point to get some additional information.

d) Defining a reproducible and practicable procedure to catch the transition noise that nobody has ever noticed is virtually impossible.

e) If in the future there is a design that has clear transitional noise characteristics, the effect could be studied and, if deemed necessary, an amendment to Chapter 13 could be proposed.

7.1.2 General information

GM No. 1 13.6
[Terms used in tilt-rotor noise certification procedures]

Aeroplane mode. The term "aeroplane mode" is used when the rotors are orientated with their axis of rotation substantially horizontal (i.e. engine nacelle angle near 0° on the "down-stops"). See GM No. 2 13.6 (3) c).

Gates. In the design of a tilt-rotor, there can be a number of preferred nacelle angle positions (fixed operation points) called "gates". These are default positions that will be used in normal operation of the aircraft.

The "gate" concept is expected to be typical for all tilt-rotors certificated to Chapter 13 of the Annex, although the number and position of the gates may vary. The gates play an important role in the airworthiness requirements, where they are defined as "authorized fixed operation points in the VTOL/conversion mode". When the aircraft is flying in the aeroplane mode, the nacelle angle will be in line with the longitudinal axis of the aircraft. In this case the angle is fixed by using the so-called "down-stop".

Helicopter mode. The term "helicopter mode" is used when the rotors are orientated with their axis of rotation substantially vertical (i.e. nacelle angle around 90°). In Chapter 13 of the Annex the condition is referred to as the "VTOL/conversion mode", which is the term used in the airworthiness standards developed for the tilt-rotor. "VTOL" refers to vertical take-off and landing capability. "Conversion" refers to the area of operation where the nacelles are tilted forward of 90° and less than 0°.

Nacelle angle. The "nacelle angle" is defined as the angle between the rotor shaft centre line and the longitudinal axis of the aircraft fuselage. The nacelle is normally perpendicular to the plane of rotation of the rotor.

7.1.3 Information on specific Chapter 13 texts

GM No. 2 13.1
[Applicability]

(1) *Applicability*

An applicability section has been added to promote uniform application of the Standards. The reference to derived versions means that no measurements are required on aircraft that are quieter than their parent aircraft due to the definition of derived versions in the Annex. The definition of "adversely" in Note 2 of the definition of "Derived version of a helicopter" in Part 1 of the Annex is also applicable to tilt-rotors.

GM 13.2
[Noise evaluation measure]

(1) *Noise evaluation measure*

Because of the similarities of tilt-rotors with helicopters, the same units as used in Chapter 8 of the Annex are used and the current Appendix 2 of the Annex is used for noise certification of tilt-rotors to Chapter 13 of the Annex. For land-use planning purposes, it is proposed that additional data be made available as per the guidelines in Attachment H of the Annex.

Chapter 13 of the Annex recommends that SEL and L_{ASmax} be calculated through additional analysis of the data that have already been measured for certification purposes. In addition, one-third-octave SPLs corresponding to

L_{ASmax} should be made available to the certificating authority for land-use planning purposes. As some of this information (e.g. one-third-octave SPLs) may be commercially sensitive, it is at the discretion of the applicant to whom it is made available.

GM 13.3
[Reference noise measurement points]

(1) *Reference noise measurement points*

The same reference noise measurement points used for Chapter 8 of the Annex are used for Chapter 13 of the Annex.

GM 13.4 and 13.5
[Maximum noise levels and trade-offs]

(1) *Maximum noise levels and trade-offs*

Because of the similarity with helicopters and the relatively low maturity of tilt-rotor technology, the current limits of 8.4.1 and the trade-offs of 8.5 of Chapter 8 of the Annex have been applied to tilt-rotors for Chapter 13 of the Annex. For the overflight case, a limit is specified only for the helicopter mode, since this is normally the noisier cruise configuration and insufficient data currently exists to define a limit for the aeroplane cruise mode.

GM No. 2 13.6
[Noise certification reference procedures]

(1) *General*

The helicopter reference procedures in Chapter 8 of the Annex have been used to define reference procedures in Chapter 13 of the Annex. The capability to change the nacelle angle and the two (or possibly more) different rotor speeds require further definition, however, of the reference procedures in Chapter 13 of the Annex from the helicopter reference procedures in Chapter 8 of the Annex.

(2) *Rotor speed*

In Chapter 13 of the Annex, the rotor speed required is linked to the corresponding flight condition. For a multiple rotor speed tilt-rotor, this means that for take-off, approach and overflight in the helicopter mode, the higher, helicopter mode rotor speed is used, while for the overflight in aeroplane mode, the lower, aeroplane mode rotor speed is used.

Note. — Tilt-rotor designs will likely have at least two possible rotor speeds: one rotor speed for the helicopter mode and another lower rotor speed for the aeroplane mode. It is anticipated that the lower rotor speed will be used only in cruising mode when the nacelles are on the down-stop, and that, before leaving the down-stop, the rotor speed will be set to the higher value needed for the tilt-rotor to be able to hover.

(3) *Nacelle and flap angles*

a) Take-off

During take-off, the choice of the nacelle angle or gate is left to the applicant to enable definition of a reference take-off condition based on the best achievable rate of climb. There will be one nacelle angle that gives the highest overall rate of climb, but this angle may or may not correspond to a gate. An applicant would normally choose the nacelle angle or gate that is closest to the nacelle angle that corresponds to the overall best rate of climb. Note that for each nacelle angle or gate there is a corresponding airspeed that gives the best rate of climb that is normally not the same numerical value for different nacelle angles. The best rate of climb airspeed V_Y is the airspeed for the best rate of climb achievable at the chosen nacelle angle or gate.

For tilt-rotors with flap angles that automatically change with flight condition, the flap angle used for noise certification is determined by the take-off conditions. For tilt-rotors with pilot control of flap angle, the flap angle for noise certification is selected by the applicant and maintained for all test runs at the reference take-off flight condition.

b) Overflight in helicopter mode

As a tilt-rotor is typically airspeed-restricted in helicopter mode, a partial tilting of the rotors is allowable. There will normally be a nacelle angle below which hover is no longer possible and for which flight with zero airspeed is not permitted. The nacelle angle selected for the overflight in helicopter mode is the gate closest to that angle.

For tilt-rotors with flap angles that automatically change with flight condition, the flap angle used for noise certification is determined by the overflight conditions. For tilt-rotors with pilot control of flap angle, the flap angle for noise certification is selected by the applicant and maintained for all test runs at the reference overflight flight condition.

c) Overflight in aeroplane mode

In overflight in aeroplane mode, the nacelle angle is defined as on the down-stop, the position that will normally be used for cruise and high speed flight. Two conditions are measured:

— one is with the high rotor speed and the same speed, as close as possible, as used in the helicopter mode overflight. This condition is intended to make it possible to make comparisons between the helicopter mode and aeroplane mode overflight; and

— the other condition is with the cruise rotor speed and speed V_{MCP} or V_{MO}, as defined in Note 1 of 13.6.3.1 e) of Chapter 13 to the Annex, which is intended to represent a worst-case cruise condition.

d) Approach

For the approach reference configuration, the nacelle angle for maximum approach noise should be used. This is in line with the philosophy of 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.

For tilt-rotors with flap angles that are automatically defined by change with flight condition, the flap angle used for noise certification is determined by the reference approach conditions. For tilt-rotors with pilot control of flap angle, the flap angle for noise certification is selected by the applicant and maintained for all test runs at the reference approach flight condition.

GM 13.7
[Test procedures]

(1) *Test procedures*

The test procedures are the same as in Chapter 8 of the Annex. Where appropriate, the helicopter guidance provided in Chapter 4 of this manual is equally applicable to tilt-rotors.

Note that this means that, as a minimum, all noise measurements are taken and evaluated with the microphone at 1.2 m (4 ft), including data taken for land-use planning purposes. See Attachment H of the Annex and Chapter 8 of this manual for additional guidance on obtaining noise data for land-use planning.

Chapter 8

GUIDELINES ON FLIGHT TEST WINDOWS AND ADJUSTMENT OF LAND-USE PLANNING NOISE DATA MEASURED IN ACCORDANCE WITH ATTACHMENT H TO ANNEX 16, VOLUME I

8.1 EXPLANATORY INFORMATION

8.1.1 Background

GM ATT H 1
[General]

At CAEP/6, guidelines for the provision of rotorcraft noise data for land-use planning (LUP) purposes were approved as Attachment H to the Annex. The objective of Attachment H is the provision of noise data, in metrics suitable for LUP purposes, at the noise certification flight conditions and/or at alternative flight conditions representing normal operating procedures or other flight procedures for noise abatement or heliport-specific requirements. These guidelines are equally applicable to tilt-rotors.

Detailed guidance on flight test windows and adjustments of LUP data to reference conditions for alternative flight procedures specifically designated for LUP data provision is provided in this chapter. To be consistent with noise certification data and provide comparable accuracy, the detailed guidance is based, to the fullest extent practical, on the flight test windows and data adjustment procedures utilized for noise certification flight procedures.

In developing these flight test windows and data adjustment procedures, the needs associated with LUP data provision have been balanced against the test costs in acquiring LUP data, with the intent of encouraging additional optional flight testing and measurements by applicants.

The guidance on test windows for alternative flight procedures is provided in 8.1.2. Guidance on adjustment of LUP data to reference conditions is provided in 8.1.3 and 8.3.1, with 8.1.3 addressing reference conditions and 8.3.1 providing specific guidance on adjustment procedures.

Note.— The test windows and adjustments to data provided in this chapter address constant airspeed and flight path conditions only. Varying airspeed and flight path conditions may require additional guidance not yet provided in this chapter.

8.1.2 Test windows

GM No. 1 ATT H 2.1 and 2.2
[Alternative constant airspeed and flight path conditions]

The flight test windows and procedures for alternative constant flight conditions for LUP are provided in Table 8-1 together with the existing requirements for noise certification. "No change" in Table 8-1 denotes the recommended use of the corresponding test window or procedure of Chapter 8 or 11 of the Annex.

Table 8-1. Flight test windows and procedures for alternative constant flight conditions for LUP

Note.— References to Doc 9501 are marked; all other references are to Annex 16, Volume I.

Annex 16/Doc 9501 reference	*Test window/procedure*	*Noise certification*	*LUP flight conditions*
8.7.4	Total adjustments	Take-off: 4 EPNdB/2 EPNdB Approach and flyover: 2 EPNdB	No change for integrated noise metrics
8.7.5	Rotor speed (N_r)	±1 per cent	No change
8.7.6	Airspeed	±9 km/h (±5 kt)	±13 km/h (±7 kt)
8.7.7	Overflights with headwind/tailwind	Equal numbers	No change
8.7.8	Angle from the vertical	±10° or ±20 m (±65 ft)	No change
8.7.9	Overflight height at overhead	±9 m (±30 ft)	No change
8.7.10	Approach angle	± 0.5° "Wedge"	No change
8.7.11	Mass	90 per cent to 105 per cent	No change
App 2, 2.2.2.4.1 b)	Temperature at 10 m (33 ft)	–10°C to 35°C (14°F to 95°F)	No change
App 2, 2.2.2.4.1 c)	Relative humidity at 10 m (33 ft)	20 to 95 per cent	No change
App 2, 2.2.2.4.1 d)	8 kHz sound attenuation coefficient	12 dB/100 m	No change
App 2, 2.2.2.4.1 e)	Wind at 10 m (33 ft)	5.1 m/s (10 kt)	No change
App 2, 2.2.2.4.1 f)	Crosswind at 10 m (33 ft)	2.6 m/s (5 kt)	No change
App 2, 3.5.2	Microphone height	1.2 m (4 ft)	1.2 m (4 ft) (Note 1)
App 2, 5.4.2	Number of test runs	6	4
App 2, 5.4.2	90 per cent CI — 3 microphone average (Note 2)	±1.5 EPNdB	±1.5 dB SEL
	90 per cent CI — each metric at each microphone	N/A	To be reported
Doc 9501, 4.2.3.2.1	No adjustment window	Equivalent to <0.3 dB delta	No change (Note 3)
Doc 9501, 4.2.3.2.2	Airspeed for equivalent Mach number	±5.5 km/h (3 kt)	No change
Doc 9501, 8.1.2	Airspeed (V_{TAS} and V(x)) — decelerating	N/A	±13 km/h (±7 kt) of reference airspeed schedule
11.6.5	Total adjustments	2 dB(A)	No change
11.6.6	Rotor speed (N_r)	±1 per cent	No change
11.6.7	Airspeed — constant	±5.5 km/h (±3 kt)	±9 km/h (5 kt) (Note 4)
11.6.4	Headwind/tailwind	Equal numbers	No change
11.6.8	Angle from the vertical	±10°	No change
11.5.2.1 a)	Height at overhead	± 15 m (±50 ft)	No change
	Approach angle	N/A	±0.5° "Wedge"
11.6.9	Mass	90 per cent to 105 per cent	No change
App 4, 2.2.2 b)	Temperature at 10 m (33 ft)	–10°C to 35°C (14 ºF to 95ºF)	No change
App 4, 2.2.2 b)	Relative humidity at 10 m (33 ft)	20 to 95 per cent	No change
App 4, 2.2.2 b)	8 kHz sound attenuation coefficient	10 dB/100 m	No change
App 4, 2.2.2 c)	Wind at 10 m (33 ft)	5.1 m/s (10 kt)	No change
App 4, 2.2.2 c)	Crosswind at 10 m (33 ft)	2.6 m/s (5 kt)	No change
App 4, 4.4.2	Microphone height	1.2 m (4 ft)	1.2 m (4 ft) (Note 1)

Annex 16/Doc 9501 reference	*Test window/procedure*	*Noise certification*	*LUP flight conditions*
App 4, 6.3.1	Number of test runs	6	4
App 4, 6.3.2	90 per cent CI	±1.5 dB SEL	No change
	90 per cent CI — each metric at each microphone	N/A	To be reported
Doc 9501, 4.2.3.2.1	Equivalent Mach number	±5.5 km/h (±3 kt)	No change

1. LUP measurements at other heights should be adjusted to 1.2 m (4 ft) using an approved method.
2. The three-microphone average is based on the three noise certification measurement points.
3. No change for Chapter 8 noise certification measurement points. Other measurement points to be evaluated.
4. Can use ±13 km/h (±7 kt) if velocity term, Δ_2, of Chapter 8 is used.

Many of the flight test windows and procedures currently used for noise certification testing can be applied when acquiring noise data for LUP purposes under Attachment H to the Annex. Thus the flight test windows and procedures detailed in Table 8-1 make as much use of current adjustment procedures of Chapters 8 and 11 of the Annex as practical. In addition, it should be noted that the “zero attenuation adjustment window” as defined in 4.2.3.2.1, may be used.

Table 8-1 includes, relative to the noise certification requirements, an expanded airspeed tolerance of ±13 km/h (±7 kt) for Chapter 8 helicopters and ±9 km/h (±5 kt) for Chapter 11 helicopters (or ±13 km/h (±7 kt) if the Chapter 8 Δ_2 adjustment is used), and a minimum number of 4 test runs. The 90 per cent confidence interval limit of ±1.5 EPNdB currently applied to the three-microphone average of EPNL in Chapter 8 is also applied to the corresponding three-microphone average of SEL. In the case of Chapter 11 helicopters, the current 90 per cent confidence interval requirement for SEL at the flight track microphone is retained. In addition, the 90 per cent confidence interval calculated for each time-integrated and maximum noise level metric at each microphone should be reported.

These guidelines primarily address the balance between LUP data needs and test costs for applicants providing data under Attachment H. In particular, increasing the airspeed test window by 3.7 km/h (2 kt) will reduce test costs while having little impact on the final results. Reducing the required minimum number of test runs from 6 to 4 also reduces test costs while the needed accuracy of the data is maintained by the 90 per cent confidence interval limit.

GM No. 2 ATT H 2.1 and 2.2
[Multi-segmented flight path conditions at constant airspeed — no climb segments]

The flight test windows and procedures provided for alternative constant flight conditions for LUP in Table 8-1 can be applied for the case of approaches with multiple reference flight path segments, each having a different constant descent angle or level flight condition. In particular, the test tolerances in Table 8-1 for total adjustments, rotor speed, airspeed, angle from the vertical, height at overhead, approach angle and test mass are applicable to each flight path segment as appropriate.

Note.— Changes in reference flight path angle between two segments should be completed as quickly as possible in order to remain within flight path tolerances for each flight segment. This may necessitate initiating the transition prior to the reference transition point.

GM No. 3 ATT H 2.1 and 2.2
[Multi-segmented flight path conditions at constant airspeed with climb segments]

(Reserved)

GM No. 4 ATT H 2.1 and 2.2
[Non-constant airspeed and flight path conditions]

(Reserved)

GM No. 5 ATT H 2.1 and 2.2
[Approaches with constant deceleration and flight path conditions]

The flight test windows and procedures provided for alternative constant flight conditions for LUP in Table 8-1 can be applied for the case of approaches with constant deceleration and flight path (glide slope) conditions with some adjustments to account for the constant variation of airspeed with time. Specifically, a reference airspeed “schedule” (i.e. reference airspeed as a function of position along the reference flight track) needs to be derived from the reference deceleration rate for the reference condition of zero wind speed. The airspeed tolerance of ±13 km/h (±7 kt) should be applied both to airspeed as a function of time and as a function of position along the reference flight track as illustrated in Figures 8-1 and 8-2.

GM No. 6 ATT H 2.1 and 2.2
[Other non-constant airspeed and flight path conditions]

(Reserved)

8.1.3 Reference conditions

GM No. 1 ATT H 2.3
[General]

Flight procedures designed to represent normal or noise abatement operations can vary from simple fixed flight path and airspeed procedures similar to noise certification test conditions to complex non-constant flight path and/or non-constant airspeed procedures. The resulting reference flight procedures and data adjustment procedures should be submitted to the certificating authority for approval.

The primary reference test conditions that affect adjustments to the noise data are the reference atmospheric conditions, the reference helicopter flight path, and the reference helicopter airspeed. For acquiring noise data for LUP purposes, the reference atmospheric conditions should be the same as those specified in 8.6.1.5 of Chapter 8 and 11.5.1.4 of Chapter 11 of the Annex.

In the process of developing flight profiles for LUP and noise abatement procedures, a reference flight path and/or reference airspeed procedure may not have been determined prior to obtaining a set of noise data suitable for LUP purposes. In such cases, the flight path and airspeed test data may be used to derive appropriate reference values. The method used should be approved by the certificating authority.

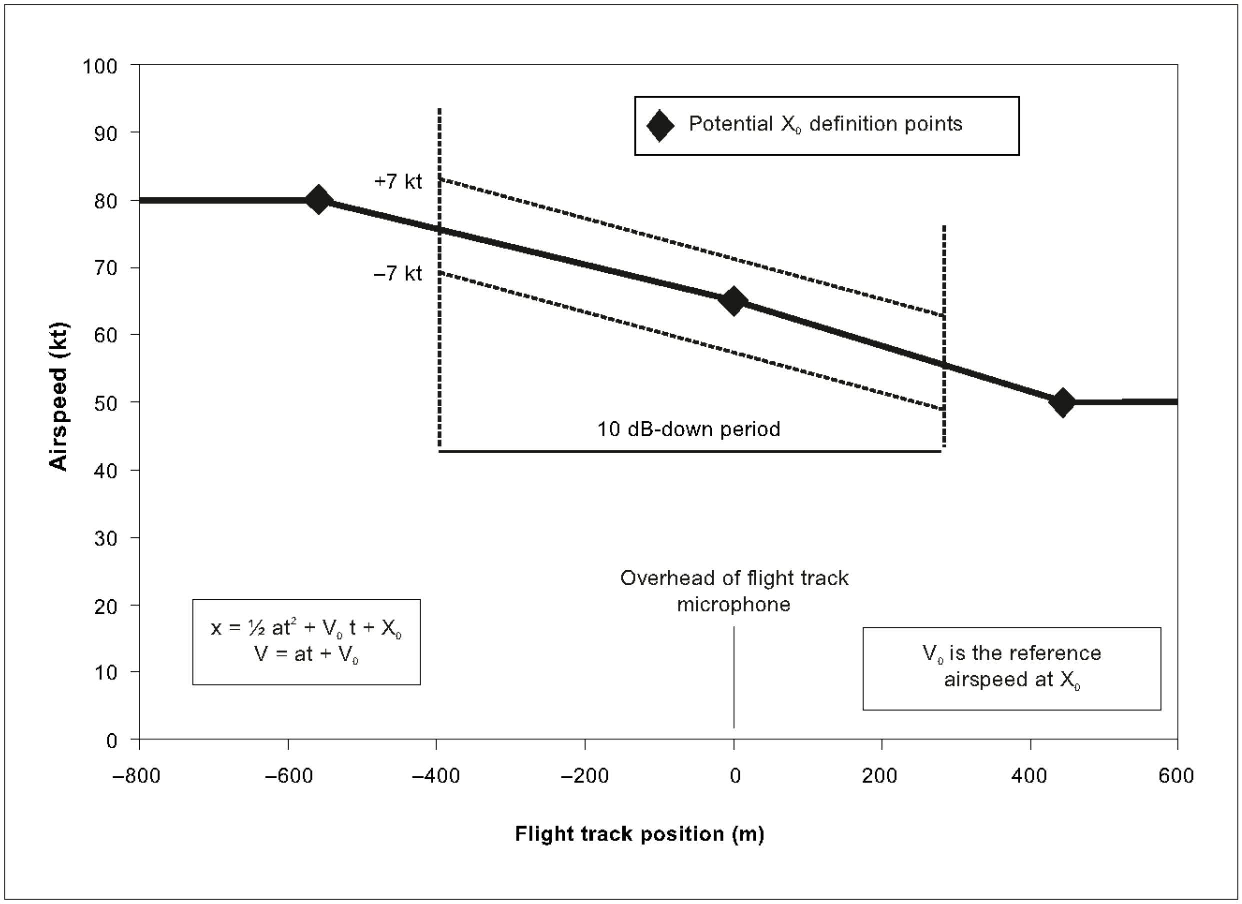


Figure 8-1. Example of a reference airspeed profile versus flight track position for a constant deceleration from 80 kt to 50 kt at 1 kt/s

GM No. 2 ATT H 2.3
[Predefined constant flight path and constant airspeed]

If a predefined reference constant flight path and constant speed conditions similar to, but different from, those defined for noise certification testing under Chapter 8 are used, the same adjustment procedures defined in Appendix 2 can be used with the new reference conditions substituted in the adjustment procedures as appropriate and the adjustment procedures modified as necessary to give results in terms of adjusted sound exposure level, L_{AE}, and any other metrics selected by the applicant.

GM No. 3 ATT H 2.3
[Derived constant flight path]

If a reference flight path is not predefined, a reference path needs to be derived or otherwise determined from the flight test data. One method to define the reference path is to determine the mean of the test runs by calculating the path of each test run using a least-squares linear fit of the aircraft position data, defined in terms of X, Y and Z coordinates, between the 10 dB-down points and averaging the calculated results.

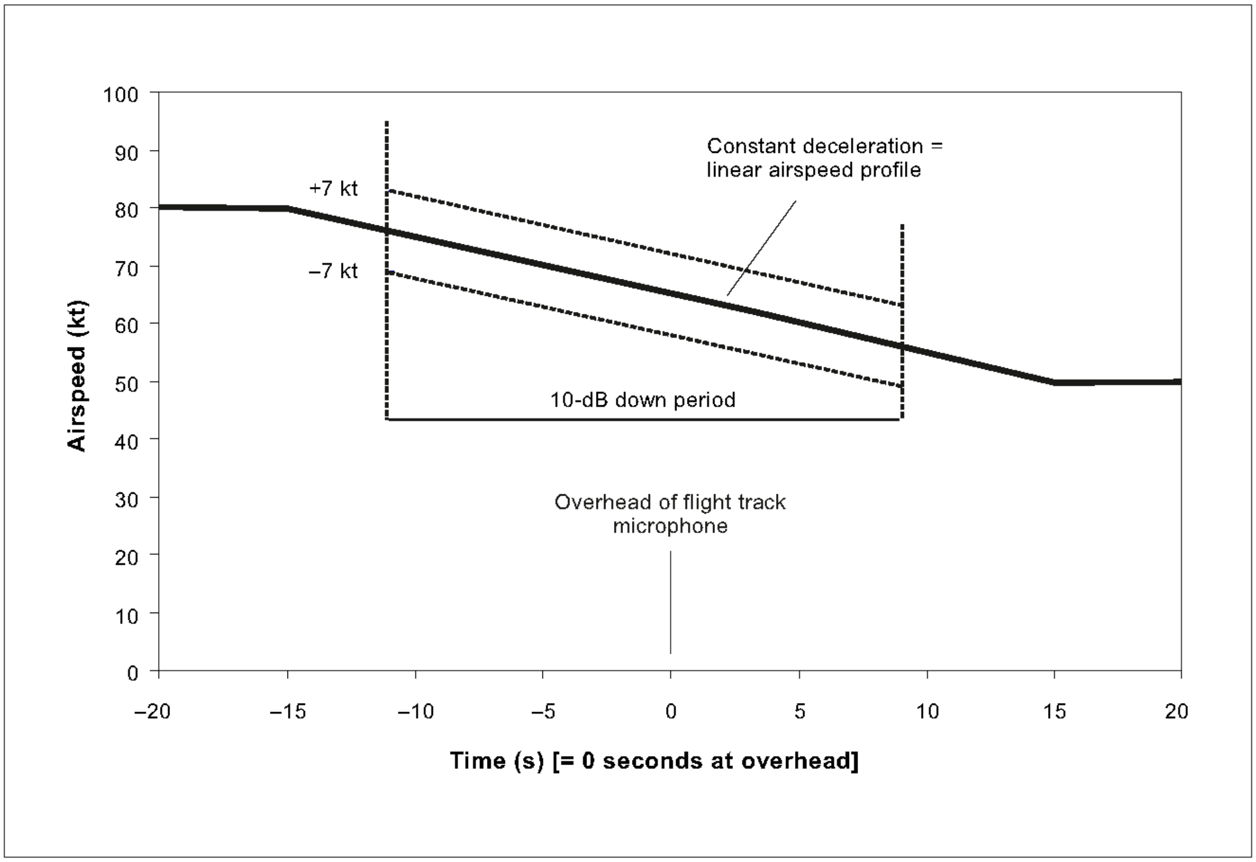


Figure 8-2. Example of a reference airspeed profile versus time for a constant deceleration from 80 kt to 50 kt at 1 kt/s

An example is the case where, as a result of flight testing multiple glide slopes, a fixed glide slope approach is deemed appropriate for pilot acceptability. If the selected flight path is repeated as necessary to obtain a statistically valid set of noise levels, the flight path data can be averaged to define the reference flight path.

GM No. 4 ATT H 2.3
[Derived constant airspeed]

If the reference airspeed, V_R, is not predefined, a value of V_R needs to be derived or otherwise determined from the measured data. One method to define V_R is to determine the mean of the test runs by averaging the true airspeeds of each test run that meets the test window criteria.

An example of this is the case where the sensitivity of noise level with airspeed and rate of descent is of interest. The test programme might incrementally test a range of fixed IAS for one or more rates of descent, with the reference airspeed for a LUP flight profile subsequently defined after the flight test programme.

For the special case of determining V_R for the flyover condition when using the equivalent Mach number method (see AMC A2 8.1.2.2 (10), 4.2.3.2.2 and GM A4) to adjust for source noise, a separate method is described in

GM No. 11 ATT H 2.3 in 8.3.1 of this chapter.

Note.— The reference ground speed, V_{GR}, can be derived from true airspeed data since, by definition, the true airspeed and ground speed are identical for the zero wind reference condition.

GM No. 5 ATT H 2.3
[Multi-segmented flight path conditions at constant airspeed]

This guidance applies to multi-segmented approach profiles at a single constant reference airspeed, with each segment having a different reference descent angle or level flight condition.

Note.— An alternative procedure for supplying LUP data for multi-segmented flight profiles at constant airspeed is possible by combining segments from constant profile data sets. The applicant should be aware, however, that directivity effects can be important in propagating acoustic data to the flight paths for each segment, necessitating the use of additional microphones to provide greater geometric resolution of the recorded noise data.

GM No. 6 ATT H 2.3
[Guidance for multi-segmented flight paths with climb segments]

(Reserved)

GM No. 7 ATT H 2.3
[Non-constant airspeeds and/or flight path conditions]

(Reserved)

GM No. 8 ATT H 2.3
[Approaches with constant deceleration and flight path conditions]

The deceleration phase of the reference flight profile should span the entire 10 dB-down period for each of the noise certification measurement points as illustrated in Figures 8-1 and 8-2. If not, the reference approach procedure should not be treated as a single flight segment. It is also advisable that the deceleration phase be initiated as close as possible to the start of the 10 dB-down period in order to ensure that the airspeed is as close as possible to the reference airspeed at the first 10 dB-down point. This will be useful in minimizing the potential effects of wind on meeting both airspeed tolerance requirements.

Note.— Practice flights may be advisable to establish and/or confirm a reference flight profile that meets these criteria.

If a reference deceleration or airspeed schedule is not predefined, its value needs to be derived or otherwise determined from the measured data. One method to define reference deceleration or airspeed schedule is to determine the mean of the test runs by averaging the deceleration or airspeed profile of each test run that meets the test window criteria.

GM No. 9 ATT H 2.3
[Other non-constant airspeeds and/or flight path conditions]

(Reserved)

8.2 EQUIVALENT PROCEDURES INFORMATION

(Reserved)

8.3 TECHNICAL PROCEDURES INFORMATION

8.3.1 Adjustments to reference conditions

GM No. 10 ATT H 2.3
[Constant airspeed and flight path conditions]

Helicopter noise data acquired for constant airspeed and flight path conditions are typically adjusted to reference conditions using standardized procedures such as provided in Appendices 2 and 4 of the Annex.

GM No. 11 ATT H 2.3
[Measurements processed using the procedures of Appendix 2 of the Annex]

The following adjustments to noise data assume corrected as-measured one-third octave and aircraft position time history data and are available in Appendix 2 of the Annex.

Note.— Corrected as-measured noise data are data corrected as per the requirements of 3.9 and 3.10 of Appendix 2 of the Annex.

If a reference flight condition with a fixed flight path and/or fixed airspeed different from those defined for noise certification testing under Chapter 8 is measured, the same data adjustment procedures defined in Appendix 2 of the Annex can be used with the new reference conditions substituted in the adjustment procedures as appropriate and the adjustment procedures modified as necessary to give results in terms of sound exposure level, L_{AE}, and any other metrics selected by the applicant.

The adjustments to be applied to time-integrated noise metrics (e.g. L_{AE} or EPNdB) should include:

a) bandsharing adjustment for tone corrected metrics such as EPNL;

b) Δ_1 adjustment for sound attenuation;

c) Δ_2 duration adjustment for time-integrated metrics; and

d) Δ_3 source noise adjustment for overflights.

Note.— The bandsharing adjustment, the Δ_1 adjustment and the Δ_3 adjustment should also be applied, as appropriate, to the maximum noise level (e.g. PNLTM, L_{ASmax}) if the value is to be published.

Δ_1 can be calculated for L_{AE} and L_{ASmax} as follows:

a) determine the aircraft position at the time that the noise at L_{ASmax} was emitted and the slant range to the microphone diaphragm;

b) determine the reference aircraft position based on the reference flight path and the reference slant range to the microphone diaphragm;

c) calculate a new reference L_{ASmax} from the one-third octave spectrum as adjusted using the equation in 8.3.2.1 of Appendix 2 of the Annex;

d) calculate Δ_1 by subtracting the test L_{ASmax} from the reference L_{ASmax} as in 8.3.2.2 of Appendix 2 of the Annex.

Note 1.— Use of the Δ_1 *adjustment derived for* EPNL *and* PNLTM *is acceptable for application to* L_{AE} *and* L_{ASmax} *noise data.*

Note 2.— If the temperature and humidity meteorological conditions are within the zero attenuation adjustment window, the reference and test slant ranges may be replaced by the reference and test distances to the helicopter when the helicopter is over the centre noise measuring point (see 4.2.3.2.1). This assumes that the measurement points are the same or close to the locations used for noise certification testing, and the aircraft slant ranges are similar to those seen during noise certification testing. If additional measurement points are used that are significantly further from the flight path, consideration should be given to the increased error that is inherently added by the increased distances.

The Δ_2 adjustment is applied only to time-integrated noise metrics. The measured and reference distance values used in determining Δ_1 adjustments to the test data may be used to determine the distance term of the Δ_2 adjustment.

An example of calculating Δ_2 for L_{AE} is:

a) determine a mean ground speed, V_G, for each test run;

b) if a reference ground speed, V_{GR}, has not been predefined, determine a reference ground speed from the test results to be used as V_{GR} in the Δ_2 adjustment; and

c) calculate Δ_2 as in 8.3.4 of Appendix 2 of the Annex from the slant ranges determined from the Δ_1 adjustment procedure, mean ground speed, V_G, of the test run, and the reference ground speed, V_{GR}.

During noise certification testing, an accepted source noise adjustment procedure for overflights is the method described in 8.3.5 of Appendix 2 of the Annex. This adjustment is normally made using a sensitivity curve of $PNLTM_R$ versus main rotor advancing blade tip Mach number. For time-integrated metrics other than EPNL, the corresponding maximum noise metric should be used in place of $PNLTM_R$.

An alternative method, the equivalent Mach number test procedure, is to calculate an adjusted reference true airspeed based on the pre-selected reference airspeed and/or test airspeed and the test-day outside air temperature (see 4.1.8, AMC A2 8.1.2.2 (10), 4.2.3.2.2 and 6.1.2, AMC A4 2.4.2). Either method is acceptable for adjusting overflight data for LUP purposes at other speeds when the reference airspeed is known beforehand.

Note.— Use of the source noise adjustment derived for EPNL *and* PNLTM *is acceptable for application to* L_{AE} *and* L_{ASmax} *noise data.*

For some overflight tests without a predefined reference airspeed, V_R, for which the equivalent Mach number method is intended to be used, test runs may be flown at selected airspeeds without first adjusting the airspeed for test-day outside air temperature. In this case, the reference airspeed, V_R, may be derived from the test data so that it includes the adjustment for source noise. This can be achieved by the following process:

a) calculate a main rotor advancing tip Mach number, M_{AT}, for each test run from the test true airspeed, V_{TAS}, the main rotor blade tip rotational speed, V_{tip}, and the speed of sound, c calculated from the on-board measurement of outside air temperature:

$$M_{AT} = \frac{V_{TAS} + V_{tip}}{c};$$

b) calculate the mean of the test advancing tip Mach numbers;

c) set the reference advancing tip Mach number, M_R, equal to the mean of the test advancing tip Mach numbers;

d) calculate V_R from the reference advancing tip Mach number, M_{ATR}, the reference main rotor blade tip rotational speed, V_{tipR}, and the speed of sound, c_R, at 25°C (77°F):

$$V_R = c_R (M_R) - V_{tipR} \text{; and}$$

e) calculate the adjusted reference airspeed V_{AR} and Δ_2 for each test run as in the normal manner (see 4.1.8, AMC A2 8.1.2.2 (10), 8.3.4 of Appendix 2 of the Annex and 5.2.3 of Appendix 4 of the Annex).

Note.— A value of V_R can be selected that is different from that calculated above, with V_{AR} adjusted accordingly, as long as each test run used to determine the mean noise level for the chosen V_R is within the test window for airspeed.

GM No. 12 ATT H 2.3
[Measurements processed using the procedures of Appendix 4 of the Annex]

Note 1.— Chapter 11 applicants are encouraged to record the sound pressure signals and/or one-third octave data and, if possible, aircraft position time history data in addition to the requirements of Appendix 4 of the Annex. This will enable additional analysis and provision of data, including additional sound metrics.

Note 2.— In addition to the centre microphone required by Chapter 11, applicants should give consideration to acquiring data using two additional measurement points symmetrically disposed at 150 m (492 ft). The adjustments in this section can be applied to the noise levels measured at those locations. This requires the calculation of the slant range distance from the aircraft position at the overhead point to the sideline location.

The following adjustments assume corrected as-measured data obtained from an integrating sound level meter and aircraft position at the overhead point and are available in Appendix 4 of the Annex. When as-measured one-third octave data are used to calculate L_{AE}, the method described in GM No. 11 ATT H 2.3 can be used if aircraft time history position data are also available.

Note.— Corrected as-measured noise data are data corrected as per the requirements of 4.3.5 of Appendix 4 of the Annex.

The adjustments to be applied to time-integrated noise metrics (e.g. L_{AE}) should include:

a) Δ_1 adjustment separated into spherical spreading and duration terms (see example below); and

b) Δ_2 adjustment.

Note 1.— The separation of the Δ_1 adjustment into spherical spreading and duration terms is based on the terms specified in Appendix 2 of the Annex.

Note 2.— The spherical spreading term of the Δ_1 adjustment should be applied to the maximum noise value *(e.g.* L_{ASmax}*) if the value is also to be provided.*

An example of calculating Δ_1 is:

a) determine the slant range distance, SR, from the aircraft to the microphone using the measured aircraft height, H, when the helicopter is over the centre noise measuring point. For the flight track microphone, SR will equal H;

b) determine the reference slant range, SR_R, to the microphone using the reference flight path; and

c) calculate spherical spreading term of Δ_{1SS} as follows:

$$\Delta_{1SS} = 20 \log (SR / SR_R).$$

The duration term of the Δ_1 adjustment need be applied only to the time-integrated metric and is calculated as follows:

$$\Delta_{1D} = -7.5 \log (SR / SR_R).$$

The Δ_2 adjustment need be applied only to the time-integrated noise metric. For overflights, the equation described in 5.2.3 of Appendix 4 of the Annex and reproduced here should be used to calculate Δ_2.

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

where V_{AR} is the adjusted reference true airspeed.

To calculate the Δ_2 adjustment for take-off and approach flight conditions, the ground speed of each test run is required. However, neither Chapter 11 nor Appendix 4 of the Annex require measurement of the ground speed, V_G. If each test run is performed with a headwind component, then it is considered acceptable that a Δ_2 adjustment need not be calculated. Note, however, that the resulting noise level will be higher than if adjusted. If ground speed is measured, then Δ_2 should be calculated using the following equation:

$$\Delta_2 = 10 \log (V_G / V_R),$$

where V_R is predefined or calculated as in GM No. 7 ATT H 2.3.

GM No. 13 ATT H 2.3
[Multi-segmented flight path conditions at constant airspeed]

Because of the multiple flight segments, determination of Q_r to define a Q_rK_r distance may not be feasible. Alternatively, if Q_rK_r cannot be located on the reference flight profile, the minimum distances to the test and reference flight profiles can be used to approximate the ratio of Q_rK_r to QK in determining the Δ_1 and Δ_2 adjustments. The determination of minimum distances should be made to ensure that the adjustments to data are based on distances from the corresponding flight segment on both the test and reference profiles.

GM No. 14 ATT H 2.3
[Non-constant airspeed and flight path conditions]

(Reserved)

GM No. 15 ATT H 2.3
[Approaches with constant deceleration and flight path conditions]

If a predefined constant reference flight path equivalent to or similar to that defined for noise certification testing under Chapter 8 is used, the Δ_1 adjustment and the first (distance) component of Δ_2 adjustment defined in Appendix 2 of the Annex can be used with:

a) the new reference conditions substituted as appropriate; and

b) the adjustment procedures modified as necessary to give results in terms of adjusted sound exposure level, L_{AE}, and any additional metrics selected by the applicant.

For the constant reference airspeed conditions of noise certification under Chapter 8 of the Annex the second term of the Δ_2 adjustment uses a ground speed ratio to effect a duration adjustment to the measured noise levels. Because the reference airspeed is constant, this ground speed ratio is a time ratio. With a non-constant reference airspeed due to deceleration, however, a single reference ground speed is not available and the second term of the Δ_2 duration adjustment is better determined directly from reference and test-time deltas defined for each test run. In this case, the Δ_2 adjustment is modified to:

$$\Delta_2 = -7.5 \log (QK / Q_r K_r) + 10 \log (d_R / d)$$

where d_R is the reference flight path time interval between the test run 10 dB-down time points and d is the test time interval of the 10 dB-down period for test run *j*.

Times for the first and last 10 dB-down points on the reference profile can be determined by the following procedure:

a) distance along the reference flight profile can be represented by:

$$X_{\mathbf{r}} = \tfrac{1}{2}\, a \times t^2 + V_0 \times t + X_0,$$

where a is the reference deceleration, V_0 is the reference airspeed at X_0, and X_0 is the selected reference flight track coordinate, typically at the initiation of the deceleration, overhead of the flight track microphone, or at the termination of the deceleration.

b) for each measurement point for each test run, *j*, time *t* can be incremented until the calculated $X_{\mathbf{r}}$ coordinate agrees with the $X_{\mathbf{T}}$ coordinates of the first and last 10 dB-down points to determine the corresponding times on the reference flight profile. Alternatively, the solution to the quadratic equation can be used to directly calculate t_{first} and t_{last} as a function of *x*, i.e.:

$$t = \frac{-V_0 + \sqrt{V_0^2 - 4(0.5a)(X_0 - x)}}{2(0.5a)};$$

c) d_R is then given by the difference between these two time values.

GM No. 16 ATT H 2.3
[Other non-constant airspeed and flight path conditions]

(Reserved)

Chapter 9

GUIDELINES FOR AIRCRAFT RECERTIFICATION

9.1 INTRODUCTION

Recertification 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 certificated". The guidelines presented in this chapter are limited to recertification to Chapters 4 and 14 of the Annex. The recertification of helicopters and light propeller-driven aeroplanes to a different Standard from that to which they were originally certificated is not considered.

Noise recertification 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 recertification basis should be the date of acceptance of the first application for recertification.

Section 9.2 of this chapter is concerned with the assessment of existing approved Chapter 3 noise levels associated with applications for the recertification of an aeroplane. Section 9.3 includes guidelines for the recertification of aeroplanes specially "modified" in order to achieve recertification. The appropriate process for determining the compliance of a recertificated aircraft with a new Standard should be determined by the aircraft's certification noise levels and the associated substantiation documents. To illustrate the principle of recertification a flow chart describing the process for the recertification of subsonic jet aeroplanes from Chapter 3 to Chapter 4 is presented in Figure 9-1.

In the application of these recertification guidelines, existing arrangements between certificating authorities should be respected. It is expected that bilateral arrangements will facilitate the mutual recognition between authorities of approvals granted in accordance with the guidelines recommended in this manual.

9.2 ASSESSMENT CRITERIA

9.2.1 General

Section 9.2 is concerned with the assessment of existing approved noise levels associated with applications for the recertification of an aeroplane from Chapter 3 or 5 to Chapter 4 or Chapter 14 of the Annex. Section 9.3 is concerned with the recertification of an aeroplane from Chapter 2 of the Annex. Section 9.4 is concerned with the recertification of an aeroplane from Title 14 of the United States Code of Federal Regulations (CFR), Part 36, Stage 3.

In applying the assessment criteria of each section, if the applicant is able to answer in the affirmative, to the satisfaction of the certificating authority, all the questions that may be relevant then reassessment is not required. The existing approved Chapter 3, Chapter 5 or Stage 3 noise levels of the aeroplane should be used to determine compliance with the new Standard. Otherwise, in order to satisfy the requirements of the certificating authority, the applicant may propose additional analysis or data. Such analysis may lead to an adjustment being applied to the existing approved Chapter 3, Chapter 5 or Stage 3 noise levels. Applicants, at their discretion, may elect to provide new test data in place of, or in addition to, the analysis.

Note.— The certificating authority's assessment of the suitability of the existing approved noise levels for *compliance with the requirements of Chapter 4 and Chapter 14 will include a review of any equivalencies proposed by the applicant to meet the assessment criteria.*

9.2.2 Recertification from Chapters 3 or 5

Noise levels already approved to Chapter 3 or 5 and submitted in support of applications for recertification of existing aircraft should be assessed against the criteria presented in this section. These criteria have been developed to ensure satisfactory compliance with the new Standard. The criteria consist of a list of simple questions concerning the manner in which the original Chapter 3 or Chapter 5 data were obtained and subsequently processed. The questions are the result of a comparison of the various amendments and revisions to the Annex and to this manual to which an aircraft's existing Chapter 3 and Chapter 5 noise levels may have been approved.

For aeroplanes that were approved in accordance with Amendment 8 or higher to the Annex a reassessment is not required. The aeroplane's existing approved Chapter 3 or Chapter 5 noise levels should be used to determine compliance with the new Standard.

For aeroplanes that were approved in accordance with Amendment 7 or lower to the Annex the applicant should be required to show that the existing approved Chapter 3 or Chapter 5 noise levels are equivalent to those approved to Amendment 8 by answering the following questions. Unless otherwise noted, section references refer to either Amendment 8 to the Annex or to Working Group Approved Revision 6 (WGAR/6) of this manual.

For all aeroplanes:

a) Was full take-off power used throughout the reference flight path in the determination of the lateral noise level? (See 3.6.2.1 c) of Chapter 3 of Amendment 11 to the Annex.)

b) Was the "average engine" rather than the "minimum engine" thrust or power used in the calculation of the take-off reference flight path? (See 3.6.2.1 a) and 3.6.2.1 g) of Chapter 3 of Amendment 11 to the Annex.)

   Note.— The applicant may demonstrate compliance with Chapter 4 requirements by determining the lateral and flyover noise levels by adding a delta dB corresponding to the difference between the average and the minimum engine, as derived from approved NPD data based on the aeroplane performance changes due to this difference.

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 in the calculation of the sound propagation path duration correction term? (See 8.3.4.2 in Appendix 2 of Amendment 11 to the Annex.)

d) Was the take-off reference speed between V_2 + 10 kt and V_2 + 20 kt? (See 3.6.2 d) of Chapter 3 of Amendment 11 to the Annex.)

   Note.— The take-off reference speed used to demonstrate compliance with Chapter 4 requirements shall meet the requirements of 3.6.2 d) of Chapter 3 of Amendment 11 to the Annex.

e) Was the four half-second linear average approximation to exponential averaging used and, if so, were the 100 per cent weighting factors used? (See 3.7.5 of Appendix 2 of Amendment 11 to the Annex.

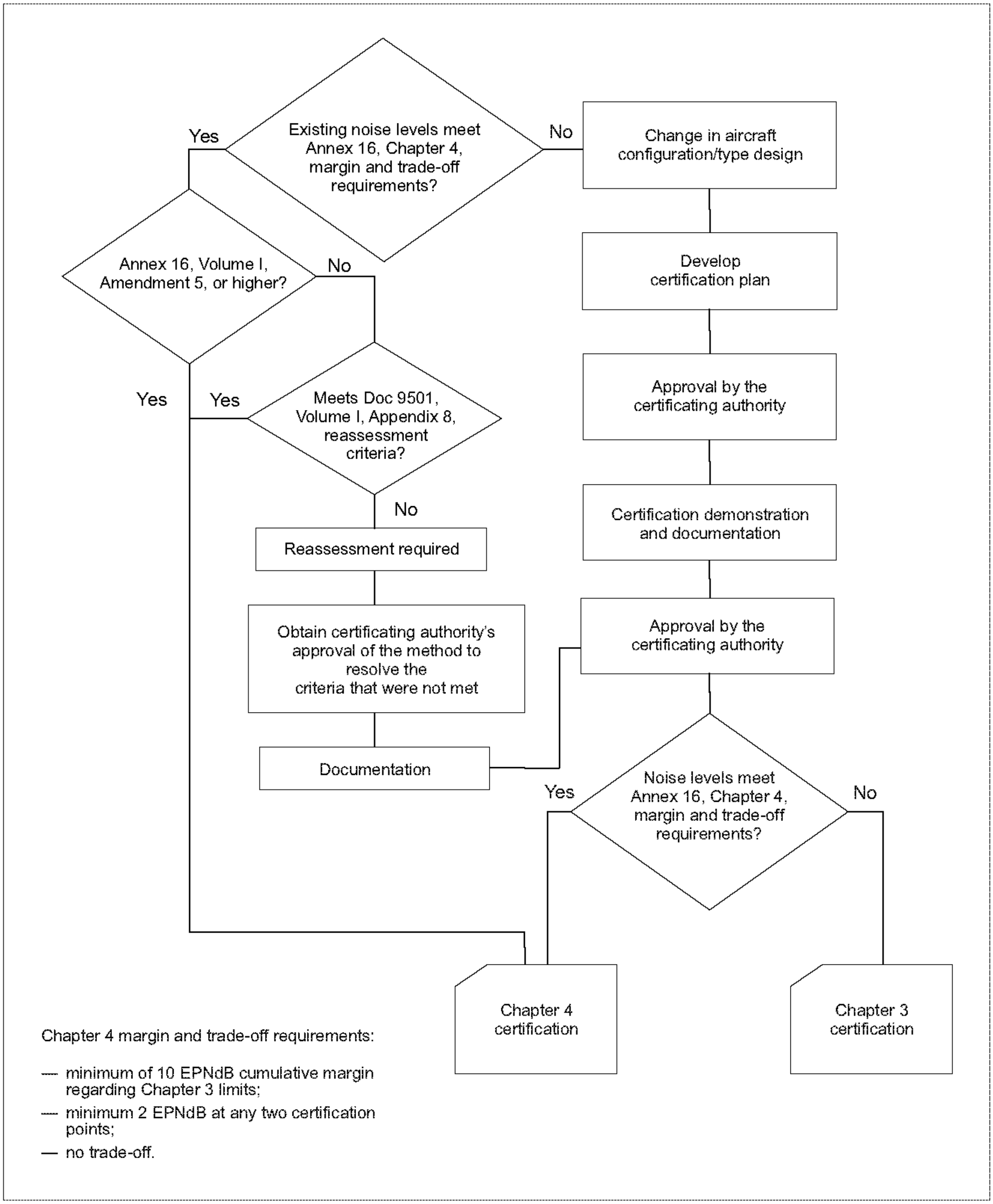


Figure 9-1. Example of "Road map" for recertification of subsonic jet aeroplanes to Chapter 4

Note.— The applicant is required to demonstrate compliance with the requirements of 3.7.5 of Appendix 2 of Amendment 11 to the Annex which equate to an exponential averaging process for the determination of SLOW weighted sound pressure levels. Simulated SLOW weighted sound pressure levels may be obtained by using one of the two equations described in 3.7.5 of Appendix 2 of Amendment 11 to the Annex as appropriate, or by other methods as approved by the certificating authority.

For jet aeroplanes only:

f) Were the noise measurements conducted at a test site below 366 m (1 200 ft), and if not, was a jet source noise correction applied? (See 4.3.2.3 of SGAR/1 of this manual.)

g) Do the engines have bypass ratios of more than 2, and if not, was the peak lateral noise established by undertaking a number of flights over a range of heights? (See 4.2.1.1.3 of SGAR/1 of this manual.)

h) In the event that "family" certification methods were used, were the 90 per cent confidence intervals for the pooling together of flight and static engine test data established according to the guidance in this manual? (See 3.5.6 of SGAR/1 of this manual.)

i) Do the engines have bypass ratios of 2 or less, and if not, in the event that "family" certification methods were used, did all associated static engine tests involve the use of a turbulence control screen (TCS) or ICD? (See 4.2.1.3.3.2 of SGAR/1 of this manual.)

For propeller-driven aeroplanes only:

j) For applications for recertification submitted on or before 19 March 2002 were either:

  - symmetrical microphones used at every position along the lateral array for the determination of the peak lateral noise level (See 3.3.2.2 of Chapter 3 of Amendment 8 to the Annex.); or

  - was the lateral full take-off power noise level determined for a point on the extended centre line of the runway 650 m vertically below the climb-out flight path? (See 3.3.1(a)(2) of Chapter 3 of Amendment 8 to the Annex.)

k) Was the approach noise level demonstrated at the noisiest configuration? (See 3.6.3 e) of Chapter 3 of Amendment 11 to the Annex.)

l) Was the target airspeed flown during the flight tests appropriate to the actual test mass of the aeroplane? (See 4.2.2.1.2 a) of Chapter 4 of SGAR/1 of this manual.)

m) For applications for recertification submitted after 19 March 2002 was the lateral full take-off power noise level determined for a point on the extended centre line of the runway 650 m vertically below the climb-out flight path? (See 3.3.1(a)(2) of Chapter 3 of Amendment 8 to the Annex.)

9.2.3 Recertification from Chapter 2 to Chapter 4

Many aircraft originally certificated to the Standards of Chapter 2 of the Annex may have already been recertificated to the Standards of Chapter 3. In such a case the approved Chapter 3 noise levels may be assessed for compliance with the new Standard according to the criteria of 9.2 of this chapter. For a Chapter 2 aircraft not already recertificated to Chapter 3, noise data originally developed to demonstrate compliance with the requirements of Chapter 2 should first be corrected in an approved manner to the requirements of Chapter 3 of the Annex before the aircraft is assessed against the requirements of the new Standard.

In the assessment of data submitted in support of an application for the recertification of an aeroplane from Chapter 2 to Chapter 3, the recommendations of 9.3.2.1 should be followed.

9.2.4 Recertification from Chapter 4 to Chapter 14

Approved Chapter 4 noise levels may be assessed directly against the maximum noise levels defined in 14.4. of Chapter 14 of the Annex for:

a) aircraft originally certificated according to the Standards of Chapter 4 of the Annex;

b) jet aeroplanes recertificated to the Standards of Chapter 4 of the Annex; or

c) propeller-driven aeroplanes recertificated to the Standards of Chapter 4 of the Annex for which the lateral full take-off power noise level was determined for a point on the extended centre line of the runway 650 m vertically below the climb-out flight path (See 3.3.1(a)(2) of Chapter 3 of Amendment 8 to the Annex.)

9.2.5 Recertification from United States 14 CFR Part 36, Stage 3, to Chapter 4

Noise levels already approved to United States 14 CFR Part 36, Stage 3, and submitted in support of applications for recertification of existing aircraft to Chapter 4 or Chapter 14 should be assessed against the criteria presented as follows.

For Stage 3 aeroplanes that were approved in accordance with 14 CFR Part 36, Amendment 24 (effective date 7 August 2002) or higher, the only assessment criterion of 9.2 of this chapter that may not have been satisfied is criterion g). Aside from consideration of criterion g), the existing approved 14 CFR Part 36, Stage 3, noise levels of the aeroplane should be used to determine compliance with the new Standard.

For Stage 3 aeroplanes that were approved in accordance with Amendments 7 through 23 of 14 CFR Part 36, in addition to the reassessment criteria of 9.2 of this chapter, the following criteria should also be considered:

a) Was the speed component of the EPNL duration adjustment determined by using 10 log V / V_R? (See 9.3.3.2 of Appendix 2 of Amendment 5 to the Annex.)

b) For derivative engine certifications using static engine test procedures, is the summation of the magnitudes, neglecting signs, of the noise changes for the three reference certification conditions between the “flight datum” aeroplane and derived version not greater than 5 EPNdB, with a maximum 3 EPNdB at any one of the reference conditions? (See 4.2.1.3.2 of Chapter 4 of WGAR/6 of this manual.)

Note.— These limitations may be exceeded under the circumstances described in Chapter 4, 4.2.1.3.2.

9.3 RECERTIFICATION GUIDELINES FOR "MODIFIED"AEROPLANES

An existing aeroplane may have been approved with Chapter 3 or Chapter 5 certification noise levels that are higher than the maximum levels required by Chapter 4 or Chapter 14. For such an aeroplane to be considered for recertification to the new Standard, it will be necessary to "modify" the aeroplane in order to lower its noise levels below the required limits. In order that certificating authorities evaluate applications for recertification of "modified" aeroplanes in a consistent manner, the guidelines described in this section should be followed. These guidelines will be developed to cover other "modification" possibilities.

9.3.1 Operational limitations

Operational limitations may be imposed on a recertificated aircraft as a condition of compliance with the new noise certification requirements. In this context, an "operational limitation" is defined as a restriction on either the configuration or manner in which an aircraft may be flown, which is applied in such a way that it is dependent on the will of the pilot and may otherwise be breached.

9.3.1.1 *Flap deflection*

For the noise certification demonstration on approach:

a) Only the most critical flap deflection (i.e. that which gives the highest noise level) shall be certificated. Noise levels for other flap deflections may be approved only as supplementary information and should be determined in conformity with 3.6.1, 3.6.3 and 3.7 of Chapter 3 of the Annex and 3.2.1.1 and 3.2.1.2 of this manual by using the same demonstrations as for the most critical flap deflection.

b) Typically for a jet aeroplane, the most critical flap configuration is associated with the maximum flap deflection. If the aircraft in its original state cannot comply with the requirements at the maximum flap deflection or, if an applicant wishes to have an aircraft certificated at less than maximum deflection, the flap deflection must be limited by means of a physical limit which, for the sake of prudence, may be frangible. A simple flight manual limitation is not acceptable. It is permitted to exceed the frangible limit only in the case of an emergency situation, defined here as an unforeseen situation that endangers the safety of the aeroplane or persons, necessitating the violation of the operational limitation. In such cases the frangible device must be replaced according to established maintenance practices and the replacement recorded in the aircraft log before the next flight. Reference to emergency exceedance of the frangible limit must be incorporated into only the emergency procedures section of the AFM.

c) It is necessary to either actually fly the approach profile defined in 3.6 of Chapter 3 of the Annex or, if the reference profile is not flown, the effect of all parameters (e.g. aircraft incidence angle) that may influence the noise levels must be shown and suitable corrections to the test results applied.

d) It should be noted that in the case of a recertificated propeller-driven aeroplane, the most critical flap configuration may not be associated with the maximum flap deflection, and all normally permitted flap deflections must be flown in order to determine the noisiest configuration.

9.3.1.2 *Propeller speed*

The demonstration of the certification noise level on approach must be made with the aircraft in its most critical configuration (i.e. that which produces the highest noise level). For propeller-driven aeroplanes, the configuration includes the propeller rotational speed. For a recertificated propeller-driven aeroplane, only the noisiest propeller speed defined for normal operation on approach may be approved. It should not be acceptable to define an alternative normal procedure using a different "quieter", typically slower, propeller speed. A noise level for such a procedure may be approved as supplementary information only.

9.3.1.3 ***Maximum authorized take-off and landing mass***

It may be possible to lower the certification noise levels of an aeroplane by lowering its maximum authorized take-off and/or landing mass. An individual aircraft shall be certificated at only one pair of maximum take-off/landing mass at any one time. Noise levels for other take-off/landing mass may be approved only as supplementary information.

9.3.1.4 ***Take-off thrust de-rate***

If a de-rating in take-off thrust is used, a method for control of this thrust is required. The methods that may be available, at the discretion of the certificating authority, could include a physical or electronic control, engine re-designation, and a flight manual limitation. De-rated take-off thrust defined for noise purposes must be equal to the take-off operating thrust limit for normal operation and may be exceeded in an emergency situation. In all cases the flight manual limitations and performance sections must be consistent.

9.3.2 Demonstration methods

9.3.2.1 ***Demonstration of lateral noise measured at 650 m***

The location of the noise measurement points for measuring lateral noise is defined in Chapter 2 of the Annex as being along a line parallel to, and 650 m (2 133 ft) from, the extended runway centre line. In the case of an aeroplane to be recertificated to Chapters 4 or 14, but initially certificated as Chapter 2, lateral noise data taken at a lateral offset of 650 m (2 133 ft) shall be acceptable only if they are corrected to an offset of 450 m (1 476 ft) by means of the "integrated" method of adjustment. In such cases, at any particular time, the "measured" and "reference" sound emission angles must be the same.

9.3.2.2 ***Centre of gravity position during take-off***

The demonstration of approach noise level must be made with the aircraft in its most critical configuration (i.e. noisiest). Configuration includes the location of the centre of gravity position which, for approach, is most critically fully forward. No such restriction exists for the demonstration of take-off noise levels, and the applicant is therefore free to select any configuration provided it is within the normal limits defined in the flight manual. In the case of a recertificated aeroplane, the centre of gravity position used in the definition of the reference take-off profile must be within the normal certificated range.

Appendix 1

REFERENCES

1. American Institute of Aeronautics and Astronautics, *Global Positioning System: Theory and Applications*, Volume I, 1996.

2. Bureau Central de la Electrotechnique Internationale, *Electroacoustics — 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*, IEC 61265, April 1995.

3. Bureau Central de la Electrotechnique Internationale, Electroacoustics — *Octave-band and Fractional-octave-band Filters,* IEC 61260, July 1995.

4. Bureau Central de la Electrotechnique Internationale, *Electroacoustics — Sound Level Meters,* IEC 61672-1, 2002.

5. ESDU International plc., *The Correction of Measured Noise Spectra for the Effects of Ground Reflection*, Data Item No. 94035 (Amendment A), December 1995.

6. Fink, M.R., *Airframe Noise Prediction Method*, USA DOT Report FAA-RD-77-29, Washington, D.C., 29 March 1977.

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

8. National Marine Electronics Association, *Standards for Interfacing Marine Electronics Devices*, NMEA 0183, Version 1.5, December 1987.

9. National Marine Electronics Association, *Standards for Interfacing Marine Electronics Devices*, NMEA 0183, Version 2.0, 1 January 1992.

10. Radio Technical Commission for Aeronautics, *Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment*, DO-229C, 28 November 2001.

11. Radio Technical Commission for Maritime Services, *Recommended Standards for Differential Navstar GPS Service*, Paper 194-93/SC104-STD, Version 2.1, January 1994.

12. SAE International, *Gas Turbine Coaxial Exhaust Flow Noise Prediction*, Aerospace Information Report AIR 1905, December 1985.

13. SAE International, *Gas Turbine Jet Exhaust Noise Prediction*, Aerospace Recommended Practice ARP 876F, May 2013.

14. SAE International, *Measurement of Far Field Noise from Gas Turbine Engines During Static Operation*, Aerospace Recommended Practice ARP 1846A, March 2008.

15. SAE International, *Method for Predicting Lateral Attenuation of Airplane Noise*, Aerospace Information Report AIR 5662, April 2006.

16. SAE International, *Practical Methods to Obtain Free-Field Sound Pressure Levels from Acoustical Measurements Over Ground Surfaces*, Aerospace Information Report AIR 1672B, June 1983.

17. SAE International, *Standard Values of Atmospheric Absorption as a Function of Temperature and Humidity*, Aerospace Recommended Practice ARP 866A, March 1975.

18. Tester, B.J. and V.M. Szewczyk, *Mixing Noise: Comparison of Measurement and Theory*, American Institute of Aeronautics and Astronautics Paper 79-0570, March 1979.

19. Ueno, Mami, Kazuaki Hoshinoo et al., *Assessment of Atmospheric Delay Correction Models for the Japanese MSAS*, Proceedings of ION GPS, http://gauss.gge.unb.ca/papers.pdf/iongps2001.ueno.pdf, 2001.

20. United States Coast Guard, *Broadcast Standard for the USCG DGPS Navigation Service*, COMDTINST M16577, 1 April 1993.

21. American National Standards Institute, *Preferred Frequencies, Frequency Levels, and Band Numbers for Acoustical Measurements*, ANSI S1.6-1984 (R2011)

Appendix 2

BIBLIOGRAPHY

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

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

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

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

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

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

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

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