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Acoustics — Unattended monitoring of aircraft sound in the vicinity of airports

Acoustique — Surveillance automatique du bruit des aéronefs au voisinage des aéroports

Reference number
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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 20906 was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise*.

Introduction

This International Standard specifies requirements for reliable measurements of aircraft sound.

This International Standard describes a threshold system of sound event recognition in a complex sound situation with multiple aircraft and other sound sources. A much more complex and sophisticated system may be needed to separate the aircraft sound events from each other and from other sound sources. Such methods — which may include radar location of sources, the addition of flight information systems, directional microphones, and other methods such as distribution of specific and residual sound or pattern recognition — are not described in this International Standard.

For political reasons, it is often necessary to install sound monitors in acoustically unsuitable places. For these situations, the operator of the sound-monitoring system should be aware of a potentially substantial increase of uncertainty in the results, as discussed in Annex B. In extreme situations, the uncertainty may become so large as to make an aircraft sound measurement meaningless.

Sound monitors installed in areas with usually low aircraft sound may be deployed to document noise levels where potential future airport operations might be considered: such sound monitors have to show that there is normally only low aircraft sound and hence no measured aircraft sound events — except in the case of extraordinary circumstances when an aircraft flies close to the sound monitor. Such sound monitors may be politically necessary.

Acoustics — Unattended monitoring of aircraft sound in the vicinity of airports

1 Scope

This International Standard specifies:

a) the typical application for a permanently installed sound-monitoring system around an airport;

b) performance specifications for instruments, and requirements for their unattended installation and operation, so as to determine continuously monitored sound pressure levels of aircraft sound at selected locations;

c) requirements for monitoring the sound of aircraft operations from an airport;

d) requirements for the quantities to be determined to describe the sound of aircraft operations;

e) requirements for data to be reported and frequency of publication of reports;

f) a procedure for determining the expanded uncertainty of the reported data in accordance with ISO/IEC Guide 98-3.

This International Standard does not provide

— a method for confirming or validating predicted sound contours;

— a method for determining, validating or confirming aircraft noise certification data;

— a method for describing the sound generated by aircraft while on the ground (including ground movements and the use of auxiliary power units), except while on the runway after start of roll for departures and between touchdown and leaving the runway for arrivals.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 1996-1, *Acoustics — Description, measurement and assessment of environmental noise — Part 1: Basic quantities and assessment procedures*

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

ISO 80000-8, *Quantities and units — Part 8: Acoustics*

ISO/IEC Guide 98-3:2008, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement* (*GUM: 1995*)

IEC 60942, *Electroacoustics — Sound calibrators*

IEC 61672-1:2002, *Electroacoustics — Sound level meters — Part 1: Specifications*

IEC 61672-3, *Electroacoustics — Sound level meters — Part 3: Periodic tests*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 80000-8, IEC 61672-1 and the following apply.

3.1
aircraft operation
⟨acoustics⟩ movement (apart from taxiing) of an aircraft over or near to a sound monitor that can result in detection of the sound as an aircraft sound event

3.1.1
departure
⟨aircraft acoustics⟩ movement of an aircraft from the start of roll on take-off or from the moment when the sound can be distinguished above the residual sound (whichever is the last to occur) to when the sound becomes indistinguishable above the residual sound

3.1.2
approach
⟨aircraft acoustics⟩ movement of an aircraft from when the sound can be distinguished above the residual sound to the exit from the runway after landing or to the moment when the sound becomes indistinguishable above the residual sound (whichever is the first to occur)

3.2
sound monitor
⟨acoustics⟩ instruments and sound measuring equipment installed at a specified site for automatic and continuous measurements of the sound produced by aircraft flying over or near the microphone

3.3
sound-monitoring system
entire automatic continuously operating system deployed in the vicinity of an airport, including all sound monitors, the central station and all software and hardware involved in its operation

3.4
equivalent continuous sound pressure level
time-averaged sound pressure level
$L_{p,\mathrm{eq},T}$
ten times the logarithm to the base 10 of the ratio of the time average of the square of the sound pressure, p, during a stated time interval of duration, T (starting at t_1 and ending at t_2), to the square of a reference value, p_0, expressed in decibels

$$L_{p,\mathrm{eq},T} = 10\lg\left[\frac{\frac{1}{T}\int_{t_1}^{t_2} p^2(t)\mathrm{d}t}{p_0^2}\right]\mathrm{dB} \qquad (1)$$

where the reference value, p_0, is 20 μPa

NOTE 1 Because of practical limitations of the measuring instruments, p^2 is always understood to denote the square of a frequency-weighted and frequency-band-limited sound pressure. If a specific frequency weighting as specified in IEC 61672-1 and/or specific frequency bands are applied, this should be indicated by appropriate subscripts, e.g. $L_{p,\mathrm{A,oct,10\,s}}$ denotes the A-weighted time-averaged octave-band sound pressure level over 10 s.

NOTE 2 $L_{p,\mathrm{eq},T}$ can be interpreted as the sound pressure level of a stable and permanent sound that has the same average energy as the sound under study.

NOTE 3 Adapted from ISO/TR 25417:2007 [1], 2.3.

NOTE 4 $L_{p,\mathrm{eq},T}$ is mostly used in the following two applications: a) a series of $L_{p,\mathrm{eq},T}$, each averaged over a short time interval (typically 1 s, then called "one second equivalent continuous sound pressure level, $L_{p,\mathrm{eq,1\,s}}$", often abbreviated as "short L_{eq}") to describe the level-time history of time-varying sound, and b) single $L_{p,\mathrm{eq},T}$, averaged over long times (e.g. 1 h or longer) to describe the overall (average) sound situation.

3.5

maximum one second equivalent continuous sound pressure level

$L_{p,\mathrm{eq,1\,s,max},T}$

maximum of the equivalent continuous sound pressure level averaged over the time interval of 1 s within a stated time interval T

3.6

AS-weighted sound pressure level

$L_{p,\mathrm{AS}}(t)$

ten times the logarithm to the base 10 of the ratio of the square of the sound pressure, p, to the square of a reference value, p_0, expressed in decibels and measured with the frequency weighting A and time weighting S (slow) where the reference value, p_0, is 20 µPa

NOTE 1 For details see IEC 61672-1.

NOTE 2 Adapted from ISO/TR 25417:2007 [1], 2.2.

3.7

maximum AS-weighted sound pressure level

$L_{p,\mathrm{AS,max}}$

maximum of the AS-weighted sound pressure level within a stated time interval

3.8

***N* % exceedance level**

***N* per cent exceedance level**

$L_{p,\mathrm{AS},N,T}$

AS-weighted sound pressure level that is exceeded for N % of the time interval, T, considered

EXAMPLE $L_{p,\mathrm{AS,95,1\,h}}$ is the AS-weighted sound pressure level exceeded for 95 % of 1 h.

NOTE Adapted from ISO 1996-1:2003, 3.1.3.

3.9

aircraft sound event

data set of acoustical descriptors adequately describing a sound event produced by a single aircraft operation

NOTE Depending on the context, the words, "aircraft event" and "single event" mean an aircraft sound event.

3.10

threshold level

$L_{\mathrm{threshold}}$

any suitable user-defined sound pressure level used to optimize reliable event detection

NOTE This threshold level is different from the term to be used for calculating the exposure level.

3.11
sound exposure
E_T
integral of the square of the sound pressure, p, over a stated time interval or event of duration T (starting at t_1 and ending at t_2)

$$E_T = \int_{t_1}^{t_2} p^2(t)\,\mathrm{d}t \tag{2}$$

NOTE 1 The sound exposure is expressed in pascal squared seconds.

NOTE 2 Because of practical limitations of the measuring instruments, p^2 is always understood to denote the square of a frequency-weighted and frequency-band-limited sound pressure. If a specific frequency weighting as specified in IEC 61672-1 is applied, this is indicated by an appropriate subscript, e.g. $E_{\mathrm{A,1\,h}}$ denotes the A-weighted sound exposure over 1 h.

NOTE 3 When applied to a single event, the quantity is called “single event sound exposure” and the symbol E is used without subscript.

[ISO/TR 25417:2007 [1], 2.6]

3.12
sound exposure level
$L_{E,T}$
ten times the logarithm to the base 10 of the ratio of the sound exposure, E_T, to a reference value, E_0, expressed in decibels

$$L_{E,T} = 10\lg\frac{E_T}{E_0}\ \mathrm{dB} \tag{3}$$

where the reference value, E_0, is $(20\ \mu\mathrm{Pa})^2\ \mathrm{s} = 4 \times 10^{-10}\ \mathrm{Pa}^2\ \mathrm{s}$

NOTE 1 If a specific frequency weighting as specified in IEC 61672-1 is applied, this is indicated by appropriate subscripts, e.g. $L_{E,\mathrm{A,1\,h}}$ denotes the A-weighted sound exposure level over 1 h.

NOTE 2 When applied to a single event, the quantity is called “single event sound exposure level” and the symbol L_E is used without further subscript.

[ISO/TR 25417:2007 [1], 2.7]

3.13 Sound designations

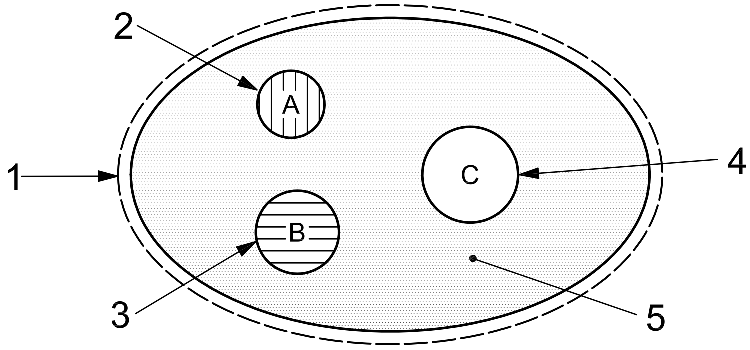
See Figure 1.

3.13.1
total sound
totally encompassing sound in a given situation at a given position and at a given time, usually composed of sound from many sources near and far

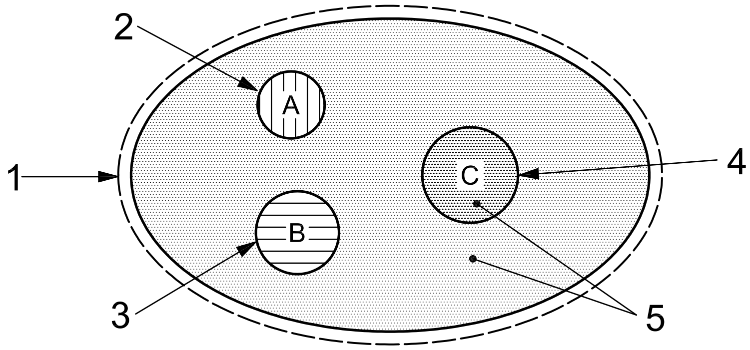
NOTE Adapted from ISO 1996-1:2003, 3.4.1.

3.13.2
specific sound
component of the total sound that can be specifically identified and which is associated with a specific source

[ISO 1996-1:2003, 3.4.2]



a) Three specific sounds under consideration, the residual sound and the total sound



b) Two specific sounds A and B under consideration, the residual sound and the total sound

Key

1 total sound
2 specific sound A
3 specific sound B
4 specific sound C
5 residual sound

NOTE 1 The lowest residual level is obtained when all specific sounds are suppressed.

NOTE 2 In a) the dotted area (5) indicates the residual sound when sounds A, B and C are suppressed.

NOTE 3 In b) the residual sound includes the specific sound C since it is not under consideration.

NOTE 4 Conceptually these specific sounds can be quite different from each other and distinct from the residual. In practice, however, it is often difficult to completely separate and measure one specific sound without any of the other specific sounds or any of the residual included, and, similarly, it is often difficult to measure the residual sound without any specific sounds included.

Figure 1 — Total, specific and residual sound designations

3.13.3
residual sound
total sound remaining at a given position in a given situation when the specific sounds under consideration are suppressed

[ISO 1996-1:2003, 3.4.3]

3.13.4
background sound
$L_{p,\mathrm{AS,res},T}$
indicator of residual sound

NOTE 1 Background sound may be estimated by the 95 % exceedance level of total sound ($L_{p,\mathrm{AS},95}$) (see 4.3.3).

NOTE 2 Some countries use $L_{p,\mathrm{AS},90}$ or $L_{p,\mathrm{AS},99}$ instead of $L_{p,\mathrm{AS},95}$ as the indicator of background sound.

3.14 Terms used for data processing

See Figure 2.

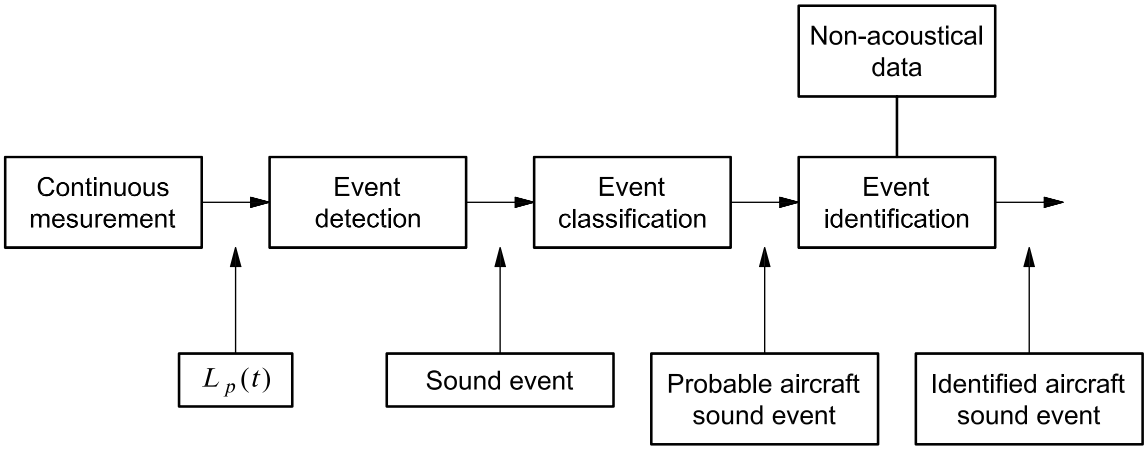


Figure 2 — Terms used for data processing

3.14.1
continuous sound measurement
uninterrupted measurement of a sound level meter (or equivalent instrument)

NOTE This measurement provides the continuous time-varying sound pressure level, $L_p(t)$.

3.14.2
event detection
extraction of discrete sound events based on acoustical criteria

3.14.3
sound event
data set containing at least the sound exposure level, the maximum sound pressure level, the duration of the event, and a time stamp

NOTE 1 To allow proper classification, the event can contain much more additional information.

NOTE 2 For the maximum short term equivalent continuous sound pressure level, see 3.5.

3.14.4
event classification
classification of sound events based primarily on acoustical knowledge

NOTE 1 Sound events can be classified into “aircraft sound events” or a “non-aircraft sound events”.

NOTE 2 Depending on the implementation, event detection and event classification can be combined in one stage.

3.14.5
non-acoustical data
⟨acoustics⟩ additional information on aircraft movements

EXAMPLE Operational information from the airport or information from systems that report aircraft position.

3.14.6
event identification
procedure for use of non-acoustical data to confirm the probable relationship of a sound event to a specific aircraft operation

3.14.7
identified aircraft sound event
aircraft sound event that is positively related to a specific aircraft operation

NOTE The data set of the identified aircraft sound event can include operational information like aircraft type, runway, and route.

4 Data acquisition

4.1 Instruments and equipment

4.1.1 General

For monitoring of aircraft sound, each measurement channel of the complete automated sound monitor, arranged as for normal use, shall conform to the electroacoustical performance specifications of IEC 61672-1 for a class 1 sound level meter. The sound monitor shall provide measurements of A-weighted measurement quantities. The frequency weighting shall conform to the specifications for response to plane progressive sound waves incident on the microphone from a reference direction representing normal (i.e. 0°) incidence on to the diaphragm of a microphone. This choice of reference direction shall be stated in the instruction manual provided by the manufacturer or supplier of the sound monitor.

For the purposes of this International Standard, a display need not be available at the sound monitor, but may take the form of a printed copy or other display method at the central station or elsewhere.

NOTE 1 For the additional requirement on extended temperature range, see 4.9.2, and for requirements concerning the instruction manual, see Clause 8.

NOTE 2 Optional one-third-octave band spectral sound measurements can be obtained.

4.1.2 Microphone assembly

The entire microphone assembly as used in normal operation (e.g. microphone, preamplifier, rain protection, windscreen, microphone device support, anti-bird devices, lightning conductor, and any calibration device) shall fulfil the following requirements: the lightning conductor shall be at least 0,5 m from the microphone; all other devices (e.g. anemometer) shall be at least 1 m below the microphone and at least 1,5 m horizontally distant from the microphone support mast.

If for practical reasons this arrangement is not possible, then the effects on the measurement uncertainty shall be documented.

4.1.3 Microphone windscreen

For all sound measurements, a suitable windscreen shall be installed around each microphone; the windscreen and its mounting are considered, for the purposes of this International Standard, as part of the microphone. The microphone-windscreen assembly should be tested to determine the A-weighted sound pressure level indication caused by a steady wind incident on the microphone at the speed of 10 m/s with the sound monitor assembled as recommended by the manufacturer or supplier. The results of this test shall be stated in the instruction manual. The A-weighted one-minute equivalent continuous sound pressure level resulting from wind sound with a wind speed of 10 m/s shall not exceed 65 dB.

4.2 Microphone mounting

4.2.1 Sound-monitoring site selection

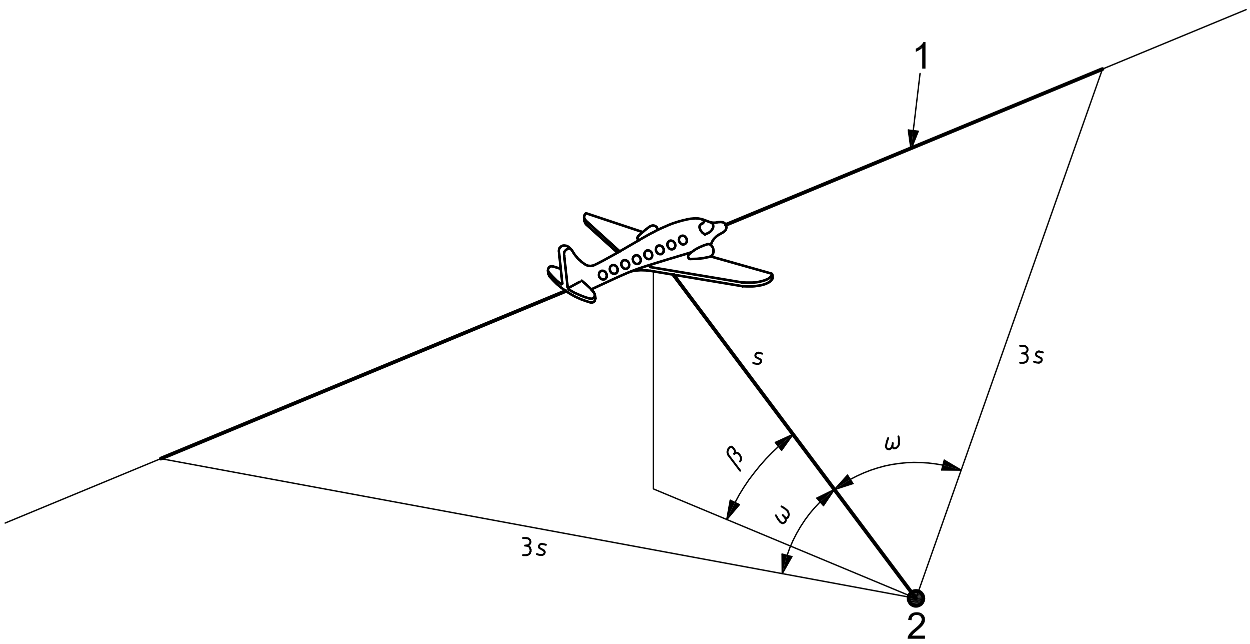
Sites for unattended measuring microphones shall be chosen to minimize the effect of residual sound (e.g. from non-aircraft sound sources).

There are always some quiet aircraft types that cannot be measured reliably because of residual sound. To provide reliable event detection using a technique based on sound level discrimination only, sites should be selected such that the maximum sound pressure level of the quietest aircraft to be detected is at least 15 dB greater than the residual long-term-average sound pressure level. For details, see Annex A.

NOTE Typical sources of residual sound can be main roads, factories, air-conditioning equipment, pumps, trees that rustle in the wind and attract birds, and metal roofs during rain or hail.

4.2.2 Requirements for site selection

Figure 3 shows a typical situation of a straight flight path and a microphone position. The shortest distance, s, (usually called “slant distance”) is perpendicular to the flight path. At distance, s, the aircraft generates a specific sound pressure level. When the aircraft is at a distance $3s$, the level of sound decreases by at least 10 dB due to spherical spreading. Therefore it is possible to identify that portion of the flight path that contributes to the levels of sound above ($L_{p,\mathrm{AS,max}}$ – 10 dB) or ($L_{p,\mathrm{A,eq,1\,s,max}}$ – 10 dB). In Figure 3, the angles bounded by s and the two lines $3s$ correspond to about 70° on each side of s. Hence, the following procedure applies to describe the sector seen from the microphone of the sound monitor that should be free of obstacles.



Key

s slant distance

β elevation angle of aircraft relative to ground plane

ω line-of-sight angle

1 flight path

2 sound monitor

Figure 3 — Example for lines of sight to be free of obstructions from the flight path to the sound monitor for the most important fraction of the flight path

First, determine the corridor in the sky which includes the greatest portion of all the flight paths of the aircraft movements to be monitored. If the sound monitor is intended to record events from several flight paths, repeat the procedure for each of the corresponding corridors. Then, looking from the microphone position at that corridor, imagine flight paths at the border of the corridor, which represent the extreme geometric conditions, e.g. the flight path with the lowest and the flight path with the highest elevation angle, β. For each of those flight paths, determine the line of sight from the microphone to the closest point on the flight path (the slant distance s) and identify the points on the flight paths a distance $3s$ away. For a straight flight path, this corresponds to a line-of-sight angle, ω, of about 70° on both sides of the slant distance.

NOTE 1 The estimation of the sector of twice 70° only considers spherical spreading. It represents an upper limit. In reality, the effects of atmospheric absorption and directivity influence the measured sound levels in such a way that the levels observed during the 10 dB down time, t_{10}, occur typically at angles around 60° (aircraft approaching) and at angles around 50° (aircraft departing).

Lines of sight from the sound monitor to those end points on the flight path define a sector which, to provide minimum uncertainty in the sound level measurements, should be free from acoustically relevant obstacles.

NOTE 2 For political and/or practical reasons, sound-monitoring sites are often pre-determined and sometimes may not conform fully to the requirement described above. In such cases, the user accepts that a greater uncertainty is associated with sound measurements at such sites.

4.2.3 Reflecting surfaces other than the ground

Minimize the influence of reflections from surfaces other than the ground by selecting the appropriate position for the microphone. In 4.2.2, the relevant segments of the various flight paths are identified. For the evaluation of the optimal microphone position, it may be assumed that sound propagates on straight paths from the aircraft to the microphone and that large reflecting surfaces behave like mirrors. Select the microphone position so that sound emitted from any aircraft position on the relevant segments and reflected by a surface other than the ground does not reach the microphone.

As a minimum requirement, all acoustically relevant reflecting surfaces other than the ground shall be at least 10 m away from the microphone, in order to provide minimum uncertainty in the sound level measurements.

NOTE Guidance on the effect on uncertainty of non-ideal monitoring situations is given in Annex B.

4.2.4 Microphone height

The standard microphone height shall be at least 6 m above ground. To minimize interference effects with ground reflections, microphone heights higher than 6 m are recommended, up to a height of 10 m.

NOTE 1 If lower microphone heights (e.g. 4 m) are used, the greater likelihood of ground interference effects can influence measurements of aircraft sound with dominant low frequency spectra, such as aircraft with propellers or low-bypass ratio jet engines. If spectral information is processed, ground interference effects can be detrimental for microphones located at low heights.

NOTE 2 Microphones mounted on roofs (i.e. mounted over a hard surface of limited extent) can be particularly sensitive to the interference effects of the sound reflected from the hard surface. The measured sound level depends on the elevation angle of the direct sound rays arriving at the microphone, the extent and inclination of the reflecting plane, and on the spectrum, which depends on the engine type, aircraft operation and distance, as well as how close the microphone is to the edge of the roof.

NOTE 3 Guidance on the effect on uncertainty of non-ideal monitoring situations is given in Annex B.

4.3 Preferred measured quantities

4.3.1 Continuous levels

The sound monitor shall measure continuously and shall display on demand the A-weighted sound pressure levels of the total sound in the form of time-series of 1 s or less equivalent continuous sound pressure levels and in the form of the AS-weighted sound pressure level.

4.3.2 Levels per sound event

A sound event is characterized by the sound exposure level, $L_{E,\mathrm{A}}$, and the maximum sound pressure level, $L_{p,\mathrm{AS,max}}$ or $L_{p,\mathrm{A,eq,1\,s,max}}$ (for details and additional requirements, see 5.3).

NOTE 1 In certain circumstances, only the part of a sound event above any sound monitor threshold level is described as the “event”.

NOTE 2 Not every audible aircraft sound is necessarily distinguishable as a sound event from the recorded sound levels.

The calculation of the sound exposure level of a sound event shall be performed with a resolution of 0,1 dB or better. This resolution does not imply that the measurement of sound exposure level has an uncertainty of only 0,1 dB. Any final readings of sound exposure level are not measurements but are normally computations made by the sound monitor using the basic sound exposure measurements.

4.3.3 N % exceedance levels

If exceedance levels are calculated, the time interval and the method for calculating the N % exceedance levels shall be clearly stated in the instruction manual (see Clause 8).

A minimum sampling rate of the AS-weighted sound pressure level of eight per second is recommended for minimum uncertainty.

NOTE At the time of publication, there are no International Standards for the procedures to calculate exceedance levels.

4.4 Time stamp

A sound-monitoring system for aircraft sound shall contain a reliable clock for identification of the date and time of day for each measurement of sound events and related phenomena. Clock time shall be within 2 s of actual time of day at all times. In case of power loss, clock operation shall continue within these specifications or it shall stop until reset. A clear indication of interruption of time-keeping shall be given. If there are multiple clocks in the sound-monitoring system, they shall not vary from each other by more than 2 s. The time resolution for any clock shall be 1 s or better.

Time shall be in local time. The sound-monitoring system shall provide a means to automatically account for Coordinated Universal Time (UTC) and changes from local standard time to local summer (daylight saving) time, and vice versa.

4.5 Aircraft sound event detection and classification

An automatic sound-monitoring system shall reliably and precisely detect and classify aircraft sound events. A variety of techniques can be used to detect the aircraft sound events depending on the situation. It may be necessary to use different techniques for different periods of the day.

The chosen technique shall classify the aircraft sound events precisely enough to satisfy the following three criteria.

a) The expanded uncertainty (see Clause 6) of the measured cumulated exposure level of all aircraft sound events shall not exceed 3 dB.

b) At least 50 % of true aircraft sound events shall be correctly classified as aircraft sound events.

c) The number of non-aircraft sound events which are incorrectly classified as aircraft sound events shall be less than 50 % of the true number of aircraft sound events.

To assess criteria b) and c) above, true aircraft sound event classification is obtained by manually identifying their individual time of occurrence (not using radar data), and the respective sound exposure level from either in situ observations or recordings. The test period shall include at least 20 aircraft sound events of the same type of aircraft operation each of which produces an AS-weighted sound pressure level that is at least 5 dB above the level of the background sound.

NOTE If the sound monitor incorporates the event identification stage (see 3.14), as is sometimes the case for sound monitors, the resulting “error rate” is considerably less than the figures given in a) to c) above.

4.6 Measurement range

The sound pressure level range of the sound monitor shall be at least from 30 dB to 120 dB. The linear operating range shall be at least 60 dB at 1 kHz. Sound pressure levels and sound events which were measured while an overload occurred in the instrument shall be marked.

If the lower boundary of the linear measurement range of the sound monitor is not less than the lowest actual sound pressure levels at the site or the upper boundary is not greater than the highest actual sound pressure levels at the site, there are significant additional uncertainties of measurement. To avoid these added uncertainties, the linear operating range of the sound monitor should be greater than the difference between the highest and lowest sound pressure levels at the site.

4.7 Transmission of data

4.7.1 General

Transmission of data from the various sound monitors to a central station may be by any appropriate type of data link and may be either continuous or intermittent. The transmission hardware and software shall provide for a resolution of 0,1 dB or better in all sound pressure level data and for appropriate validity checking of all transmitted data. Provision shall be made for indicating calibration status and specific periods of lost data caused by memory overflow, power loss or equipment malfunction. Invalid sound pressure levels caused by overflow or underflow of the measurement range shall be marked. Data transmission shall not increase the uncertainty of the sound measurement.

While no method of data error checking is specified in this International Standard, the method employed by any sound-monitoring system shall be clearly described by the manufacturer or supplier in the instruction manual.

It is important that each individual sound monitor be separately identified in each data transmission.

4.7.2 Data types

If the data are transmitted intermittently in batch form, each acoustic data transmission shall include at least one of the following data sets. The data specified in each set are a minimum requirement; additional data can be transmitted. Data types may be concatenated and transmitted together. The manufacturer or supplier shall supply exact details of the data transmitted, as follows.

a) For each sound event: The A-weighted sound exposure level, $L_{E,\mathrm{A},i}$, the maximum sound pressure level ($L_{p,\mathrm{AS,max},i}$ and/or $L_{p,\mathrm{A,eq,1\,s,max}}$), a time stamp (either the start time of each event or time of occurrence of the maximum sound pressure level) and the actual sound pressure level of the event detection threshold $L_{\mathrm{threshold}}$, if relevant.

b) The time history sequence of the sound pressure levels of the aircraft sound events.

The format and content of non-acoustical data is not specified by this International Standard.

Statistical data (e.g. N % exceedence levels) on the total sound together with the start and end time of each data period should be transmitted from the sound monitor.

4.8 Acoustical calibration and verification

4.8.1 Acoustical calibration

Means shall be provided to apply an acoustical calibration signal by a sound calibrator to each microphone to check the acoustical sensitivity of the measurement system. The calibration signal shall be a sinusoidal tone in the range 250 Hz to 1 000 Hz. The sound pressure level of the tone shall be in the range 90 dB to 125 dB. A coupler or other means may be provided to exclude ambient sound during calibration. Also, means shall be provided at the microphone site to read out the data corresponding to the calibration level and to adjust the latter as necessary to the sound pressure level in the cavity of the coupler at the time of checking the sensitivity. The calibrator used shall conform to the requirements of IEC 60942 for a class 1 instrument, and shall be calibrated by an accredited or otherwise nationally recognized laboratory at least once every 12 months.

Such an acoustical calibration shall be performed for each sound monitor at least once per year. More frequent calibrations (e.g. quarterly) are recommended.

The pure tone used for calibration should have a nominal frequency of 1 000 Hz. If the sound monitor has an optional C or Z frequency weighting, then that may be used to check the acoustical sensitivity at lower frequencies.

4.8.2 Automatic calibration check

Provision shall be made to check the operation of each sound monitor, and the system to which it is connected, by application of a known electrical signal in series with the microphone or by use of an actuator positioned on the diaphragm of the microphone. The signal at the output of the microphone should be a sinusoidal tone with a frequency between 990 Hz and 1 010 Hz and an equivalent sound pressure level greater than 80 dB. It shall be possible to activate this verification both at the microphone site and from the central station.

Checks of the electrical sensitivity of a sound monitor by means of remote verification of the microphone sensitivity and functionality may be useful for revealing failures, but shall not be considered as replacements for checks of the acoustical sensitivity of a measurement channel.

4.8.3 Time intervals of calibration check

Checking the signal sensitivity of any automatic sound monitor shall occur automatically at least once per day (preferably during a time of low aircraft activity). Whenever automatic sensitivity checking is taking place, the resulting sound pressure level data shall be excluded automatically through positive means from all accumulations of aircraft and non-aircraft sound. Any automated checking system shall not be initiated while a sound event is being detected, but shall be delayed until the event has finished.

It is permitted to perform a sensitivity check and simply store the deviation of the sensitivity level from a previous check without changing the sensitivity of the signal chain.

While automatic acoustical calibration is not excluded, electrostatic actuation of the microphone is the preferred method.

4.8.4 Storage of calibration check data

The initial calibration sensitivity level, and the differences between this level and the sensitivity levels subsequently measured on each day, shall be stored and reported. In addition, the standard deviation or variance of the differences in the calibration sensitivity levels shall be recorded and stored over the period between checks of acoustical sensitivity of a sound measuring channel by means of an acoustical calibrator. At least the last 12 months of such sensitivity data shall be stored by the sound-monitoring system.

This recording of any change of the sensitivity level shall not be used to “correct” measured data when a significant change in sensitivity level is shown, as the exact time at which the sensitivity changed cannot be known. Such data shall be regarded as very suspect. However, once a change has occurred and a second stable sensitivity level is achieved, it is reasonable to “correct” the data, but a record should always be made of any such correction. In general, a change of sensitivity level of more than 1,5 dB should be regarded as significant and the symptom of a fault. The reason for the change should be determined as soon as reasonably practical and any fault corrected.

The standard deviation or the variance may be preserved either by storing a calibration offset or a new overall figure or any method that allows the change of sensitivity level to be readily seen.

4.8.5 Verification of electroacoustical performances

The recommended time interval for verification of system performance is once a year. The maximum allowable interval is two years. If irregularities in the signal verification data occur, immediate verification is recommended. The electroacoustical performance of each channel of the sound monitor shall be verified periodically to conform to class 1 specifications of IEC 61672-1 in accordance with the procedures in IEC 61672-3.

A sound monitor that has not undergone such verification within the previous 24 month period shall be considered not to conform to the requirements of this International Standard, except during the first two years of use after installation.

The verification shall be performed using instruments for which the performance is traceable to relevant standards. It shall be performed by a laboratory that meets the requirements of ISO/IEC 17025 for this application or by a nationally recognized laboratory.

NOTE Accreditation of the laboratory can provide a higher level of confidence in the results of the laboratory.

4.9 Environmental characteristics

4.9.1 General

The requirements given in 4.9.2 to 4.9.4 state the allowable sensitivities of the sound-monitoring system to various environments. The components of the sound-monitoring system that are located outdoors shall conform to the specifications in IEC 61672-1 within the class 1 tolerance limits for the influence of variations from the reference environmental conditions. This requirement applies for the influence of variations in relative humidity, atmospheric pressure, alternating magnetic fields, electrostatic discharge, radio frequency fields and disturbances to the voltage of the power supply.

4.9.2 Air temperature

The components of a sound-monitoring system which are located outdoors shall conform to the class 1 tolerance limits of IEC 61672-1, which apply over a temperature range of −10 °C to +50 °C.

If temperatures outside the range −10 °C to +50 °C are regularly encountered at an airport, then the manufacturer or supplier shall provide the airport or user with details of the likely increase (if any) in measurement uncertainty as a result of the lower or higher temperatures.

Apart from the microphone assembly in some cases, the requirement for an extended temperature range may be met by including heating or cooling within the housing of the sound monitor. If such temperature regulation is used, it should be noted that in the event of failure, e.g. interruption of the power supply, measurement uncertainties may significantly increase.

4.9.3 Other outside influences

The mechanical design and installation of outdoor sound monitor equipment shall be such as to minimize damage by living creatures. Specific features that are advisable include running all cables in metal conduit, sturdy locks at all access points, and in general making the equipment inaccessible and resistant to damage.

The sound monitor operator shall be aware of the particular flora and fauna at the site of any installation and take steps to protect against damage that they may cause.

4.9.4 Power supply

A continuous method of supplying electrical power is acceptable, such as solar power or energy cells. Around airports, public supplies of electrical power are usually available. The sound-monitoring system shall comply with the power supply requirements of IEC 61672-1.

Any power back-up system should allow for continuous operation during breakdown or unusual deviations of the external power supply. The back-up system should be capable of allowing full operation for the worst expected annual supply failure at that site. Such a power supply failure should be considered to last at least as long as the duration of the longest public holiday at the location, when reinstating the supply during such a holiday may not be possible. The sound monitor manufacturer or supplier shall provide data showing the specified period of back-up is valid until the next verification and for any air temperature within the range specified in 4.9.2. The sound monitor should be able to operate for a suitable period without the main power supply.

4.10 Measurement of meteorological conditions

The following meteorological conditions shall be measured:

a) wind speed;

b) air temperature, relative humidity;

c) occurrence of precipitation.

The hourly average values should be provided.

Temperature, relative humidity and precipitation shall be measured at one or more representative sites at or close to the airport and/or the sound monitors. Wind conditions may need to be measured at more than one site to ensure acquisition of data that are representative of wind conditions at the sound monitors (especially if sound level measurements are to be used for noise limit infringement penalties).

If available, meteorological data should also be collected from the METAR (meteorological aviation routine weather report). METAR reports are updated periodically (typically hourly), so such data cannot provide instantaneous wind speed or directions.

The devices used to measure the meteorological conditions should have their function checked at least once per year.

5 Data processing

5.1 General

Figure 4 shows the stages of data collection and processing.

NOTE According to Figure 4, the “residual” sound can be corrupted and increased by the sound from “unidentified” events, “missing” events, and the sound from “corrupted” events, all of which are made part of the “residual” sound by this process. Also, according to Figure 5, the residual sound includes all verified aircraft sound that is 10 dB or more below the sound event maximum level. For these reasons, the “residual” sound as depicted in Figure 4 always exceeds the true residual sound according to 3.13.3, the sound remaining when all aircraft sound is absent. Depending on relative levels, this exceedance can be quite large.

5.2 Basic requirements

An aircraft sound-monitoring system, that may accumulate sound data at several sites on a continuous basis, can potentially produce a large quantity and variety of acoustical measures. While many of these measures may be useful in particular airport/community situations, there are two types of data that are essential in practically all cases and which therefore are specified as mandatory:

a) aircraft sound event data;

b) incomplete or corrupted data.

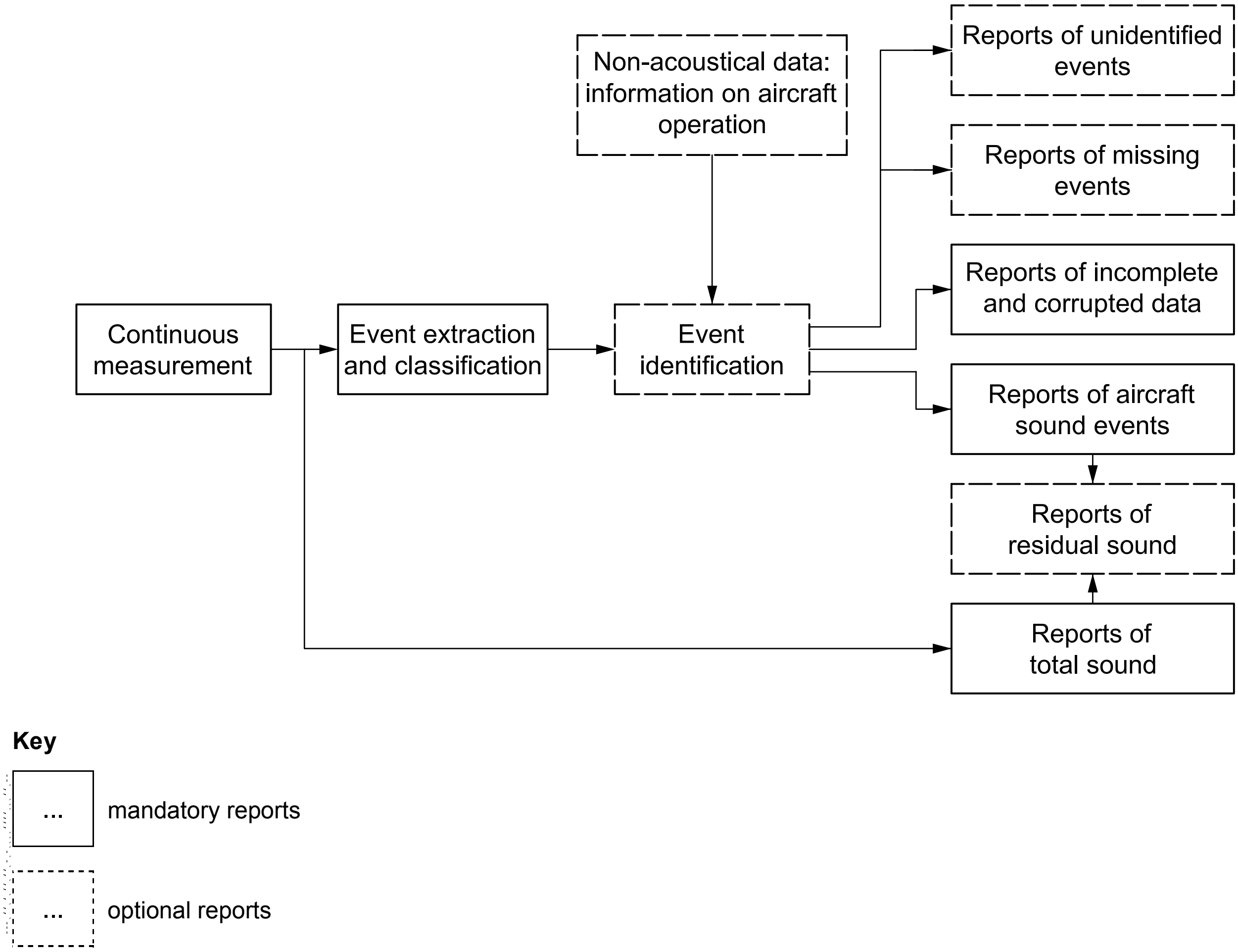


Figure 4 — Aircraft sound event data collection and processing

Total sound shall be reported over stated periods. The total sound shall be characterized by A-weighted equivalent continuous sound pressure levels over appropriate time periods. It may also be characterized by N % exceedance levels.

Exceedance levels for different time periods cannot be combined into single values for a longer time period, thus the hourly, daily and any other measures shall be calculated separately, if exceedance levels are measured.

The sound-monitoring system should store the time history of the short term $L_{p,\text{A,eq,1 s}}$ values of the events as the raw data for further investigation.

NOTE The capabilities of a sound-monitoring system can, of course, greatly exceed these basic functions, providing not only additional sound information, but also aircraft identification, runway usage, flight tracking, and other non-acoustical data.

5.3 Aircraft sound event data

5.3.1 General

In general, the sound-monitoring system first detects individual sound events from the continuous measurement. Afterwards, acoustical criteria may be applied to classify the events as likely aircraft or as non-aircraft sound events (see also Figure 2).

5.3.2 Sound event detection

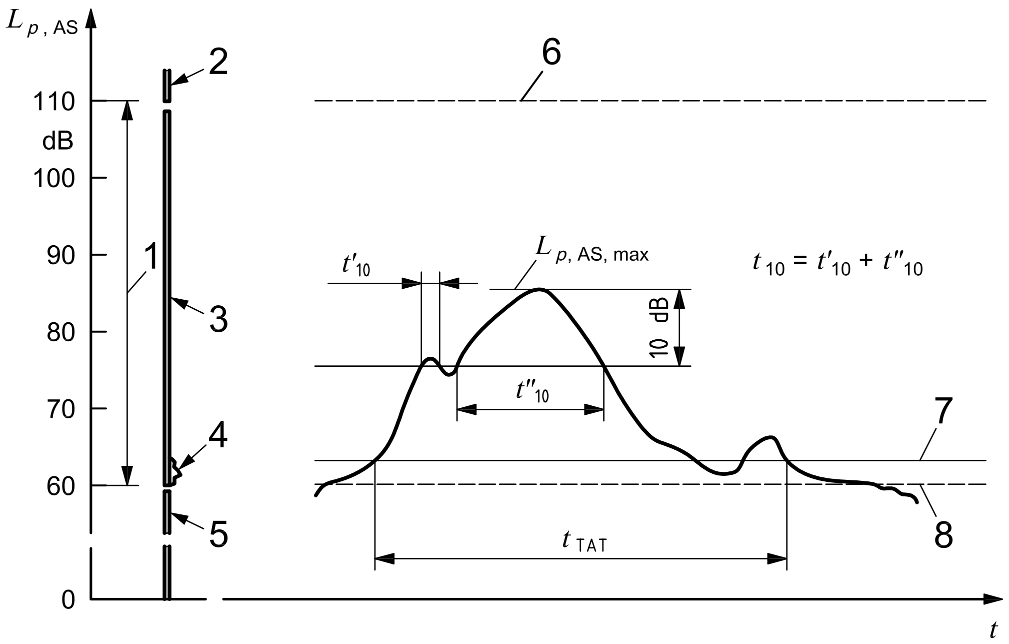
A sound event is detected when, for example, all the following acoustical criteria are satisfied:

a) the sound is not steady state, but also not impulsive, i.e. its duration lies within specified limits;

b) the sound level exceeds a threshold level by at least a specified amount;

c) when an event terminates, the sound level does not rise again above a specified level within a specified time.

NOTE The criteria are illustrated in Figure 5.



Key

$L_{p,\mathrm{AS}}$	AS-weighted sound pressure level	1	primary indicator range / dynamic range
$L_{p,\mathrm{AS,max}}$	maximum AS-weighted sound pressure level	2	overload range
t	time	3	range considered
t_{10}	10 dB down time	4	disregarded range
t_{TAT}	time above threshold	5	non-transmitted range
		6	upper limit of primary indicator range / dynamic range
		7	threshold level
		8	lower limit of linear operating range

Figure 5 — Example of event detection criteria

As a minimum, the data set required for sound event classification of a sound event number, i, consists of the maximum sound pressure level ($L_{p,\mathrm{AS,max},i}$ and/or $L_{p,\mathrm{A,eq,1\,s,max},i}$), the sound exposure level, $L_{E,\mathrm{A},i}$, the duration, T_i, and a time stamp, which is the local time either at the occurrence of the maximum sound pressure level or at the beginning of the sound event.

In addition, the sound monitor may determine the time interval between initial threshold crossing and attainment of the maximum sound pressure level, the final threshold crossing, and other potentially useful data.

5.3.3 Aircraft sound classification

Not every extracted sound event is related to an aircraft event. A classification primarily based on acoustical properties may help to separate non-aircraft sound events from aircraft events. (In 5.4, the event identification is described as a further step in data processing.)

An aircraft classification may be based on one or more of the following criteria:

a) knowledge of the range of air speed and range of distance from the microphone to the aircraft, hence of the typical duration of the sound event;

b) typical relation between maximum sound pressure level ($L_{p,\text{AS,max},i}$ and/or $L_{p,\text{A,eq,1 s,max},i}$) and the sound exposure level, $L_{E,\text{A}}$;

c) spectral information;

d) correlation with an event at another sound-monitoring site;

e) test on excessive wind speed;

f) listening to the sound recorded during the sound event.

The tests used shall be specified by the manufacturer or supplier.

5.4 Event identification

If non-acoustical data on aircraft operation are available, such as:

a) information on the flight log, runway usage, aircraft types and flight paths; and/or

b) aircraft position information,

then the sound data recorded for an aircraft may be

— further checked that they are really produced by an aircraft by correlating an aircraft sound event with the probability of an aircraft having been in the vicinity of the microphone; and

— identified to relate to a specific aircraft operation.

The identified aircraft sound event thus contains not only the basic data from the sound event, but also specific aircraft data such as aircraft type, flight path, and runway.

Such identified aircraft sound events may be formed either through an automatic process or by a human operator. In either case, it shall be possible for the operator to review the information on which the association is based and every identified aircraft sound event shall be tagged to indicate whether review and concurrence by an operator has taken place. When automatic event identification is provided, the algorithms and associated criteria used for this process at any given time shall be documented in the instruction manual.

If the criteria are changed, the changed criteria shall be stored with a logical link to the data reviewed.

If non-acoustical data are available and if the event identification is made, the instruction manual for the sound-monitoring system shall document the treatment of “unidentified events”, i.e. measured aircraft sound events which cannot be correlated to an aircraft movement (see Clause 8).

5.5 Incomplete or corrupted data

5.5.1 General

A sound monitor may cease acquiring or processing valid sound data as a result of power failure, excessive wind-induced sound, equipment malfunction, etc. Provision shall be made to alert the operator of such a condition, to promote ready resumption of operation, and to minimize loss of data. Where data are irretrievably lost or invalidated, sound level parameter calculations shall be modified appropriately to approximate the values, which would have been obtained had the loss not occurred. For example, if several hours of downtime are incurred on a certain day, the averaging process to determine the cumulative daily A-weighted average sound pressure level shall be carried out over only those hours for which data are available, rather than over the entire day. All such data shall be flagged to indicate the circumstances.

When more than one third of the data for any period are missing, no calculation shall be carried out and the record shall be left blank, with an appropriate label to indicate the circumstances.

Nothing in this subclause shall be taken as restricting the sound-monitoring system from making an estimate of the missing data, but any such estimate shall not be included in the report according to 7.2 and the fact that it is an estimate shall be clearly noted. The basis for determining any such estimate shall be clearly described in the instruction manual.

5.5.2 Wind-induced sound

Data acquired under windy conditions increase the uncertainty of the data. The wind speed at the time of each aircraft sound event should be recorded in the report. For wind speeds above 10 m/s, the measured data shall be flagged.

NOTE In some cases, wind effects may be identified by the specific spectrum of wind-induced sound (usually a low frequency dominated broad band sound).

5.6 Total sound and residual sound

The sound-monitoring system shall measure the total sound (including all sound sources). In addition it is useful that the sound-monitoring system should also calculate the residual sound and should produce time-average sound pressure levels or N % exceedance levels for the same periods as for the cumulative aircraft event data.

Such data shall be carefully distinguished from aircraft sound data in any report.

NOTE According to Figure 4, the “residual” sound can be corrupted and increased by the sound from “unidentified” events, “missing” events, and the sound from “corrupted” events, all of which are made part of the “residual” sound by this process. Also, according to Figure 5, the residual sound includes all verified aircraft sound that is 10 dB or more below the sound event maximum level. For these reasons, the “residual” sound as depicted in Figure 4, always exceeds the true residual sound according to 3.13.3, the sound remaining when all aircraft sound absent. Depending on relative levels, this exceedance can be quite large.

5.7 Data storage

Provision shall be made for both short-term and archival storage of all sound-monitoring data. As a minimum, all sound event data shall be retained as immediately accessible for a time sufficient to apply all discrimination tests and also for identification of aircraft sound events if that capability exists in the sound-monitoring system. If data are stored at remote sound monitors for periodic transmission to the central processor, each sound monitor shall have storage capacity sufficient to retain all basic sound event data and sound exposure data for the period which is the longest of:

a) twice the normal time between transmissions;

b) 24 h;

c) the longest period of absence (e.g. holiday) of sound-monitoring system administration and maintenance staff, to prevent data loss in the case of breakdown of data transmission during the time of their absence.

6 Measurement uncertainty

The uncertainty of results obtained from measurements according to this International Standard shall be evaluated, preferably in compliance with ISO/IEC Guide 98-3. If reported, the expanded uncertainty together with the corresponding coverage factor for a stated coverage probability of 95 % as defined in ISO/IEC Guide 98-3 shall be given. Guidance on the determination of the expanded uncertainty is given in Annex B.

7 Reporting of data

7.1 General

In an unattended sound-monitoring system, the “final display” as specified in IEC 61672-1 consists of the reports presented on a visual display or on a hard copy device such as a printer. While the specific format and data to be presented are matters for the user and the manufacturer or supplier to decide, some items are essential to give a balanced view of the data. Thus, this clause lists for each report the minimum data required. In addition to the mandatory International Standard data in each category, a list of additional recommended data is given. This listing does not preclude a sound-monitoring system from providing any other data. Any additional data shall be described in the instruction manual along with the details of any computations used to generate these data. The reports shall be available[1)] at the time intervals specified, but display need not be automatic and can be an operator choice. All times on reports shall be in the local time at the sound-monitoring site, although in addition UTC may be displayed as long as it is clearly distinguished from local time. The preferred descriptor of the event in each case is the A-weighted sound exposure level, $L_{E,\mathrm{A}}$, but where this is listed as mandated, the A-weighted equivalent continuous sound pressure level, $L_{p,\mathrm{A,eq}}$, or the A-weighted sound exposure can be accepted as an alternative.

Some recommended information, particularly of non-acoustical parameters, may not be available to the sound-monitoring system, unless external data are provided and are accessible to the sound-monitoring system. These include such data as flight numbers. Users should be aware that this information may be expected and arrange to provide these data.

The expanded uncertainty of reported data (see ISO/IEC Guide 98-3) shall be indicated for each sound-monitoring site.

The following site-specific information shall be reported:

a) the instruments, their calibration and layout, and the measurement time intervals;

b) a description of the operating conditions of the airport (e.g. closed runways);

c) the sound-monitoring site including the topography, the ground cover and condition.

7.2 Reporting of aircraft sound event data

7.2.1 General

Aircraft sound event data are defined as those data that are generated from one or a series of individual aircraft sound events. Each individual aircraft sound event corresponds to a single aircraft operation; each aircraft operation may correspond to events at one or more sound-monitoring sites.

The report of event data is normally more detailed than the periodic reports, such as daily, weekly, monthly or annual reports.

NOTE A report describing unidentified events or missing events can be useful.

1) “Available” does not mean that the report has to be formatted and stored in formatted form, if the information can be calculated on demand from other stored data.

7.2.2 Individual aircraft sound events

a) Information required for each aircraft event:

1) A-weighted sound exposure level over a specified duration;

2) event maximum sound pressure level ($L_{p,\text{AS,max},i}$ and/or $L_{p,\text{A,eq,1 s,max},i}$);

3) the time stamp of the event (see 4.7.2);

4) wind speed;

5) any occurrence of precipitation.

If applicable, the threshold level(s) used at each sound monitor shall be stated in the report.

b) Recommended information for each aircraft event:

1) time above the threshold(s) or 10 dB down time, t_{10}, see Figure 5;

2) N % exceedance levels for the 1 h period containing the time stamp of the event (the 1 h period beginning and ending on the hour) and the sampling rate used, as described in 4.3.3;

3) wind direction;

4) air temperature;

5) humidity;

6) flight identification;

7) aircraft type;

8) runway in use;

9) route designator (Aeronautical Information Publication, AIP) name associated with aircraft sound event;

10) departure or approach operation;

11) time history graph of the event, i.e. A-weighted short-term equivalent continuous sound pressure level, $L_{p,\text{eq,A,1 s}}$, plotted against time.

Any potentially ambiguous flight match, for example multiple overlapping events, should be flagged.

The choice of N % exceedance levels is usually determined by local regulations or codes.

The time period over which the statistical indices are produced shall be stated.

7.2.3 Cumulative aircraft sound event data

7.2.3.1 Hourly aircraft data

The equivalent 1 h average sound level corresponding to the cumulated sound exposure of all aircraft sounds occurring in each hour of a day shall be determined from the recordings provided at each sound monitor. Cumulated sound exposure at each sound monitor shall be determined by addition of the individual sound exposure of all measured aircraft sound events.

For simplicity, an individual aircraft event sound exposure shall be associated with the hour in which the time of the maximum A-weighted sound pressure level occurs during the event, even if a portion of the event falls into the preceding or succeeding hour. Otherwise, multiple events may be created as an artefact of sound monitor processing. Hours shall be identified by the local time of day at the beginning of the hour.

7.2.3.2 Daily event summary

The daily event summary report is a summary of all the aircraft sound events over a period of 24 h, for each sound monitor, usually presented in the form of a table. The calculation of different composite whole-day rating levels, L_{day}, L_{evening}, L_{night}, L_{dn}, L_{den} (referred to as "whole-day rating levels" in ISO 1996-1) harmonizes with further requirements, e.g. EU-Directives.

It is recommended that the period start at the beginning of the night as defined by local regulations (e.g. at 22:00).

7.2.4 Monthly event summary

The monthly event summary report should contain a monthly event summary, which lists by day in sequence:

a) total number of measured aircraft sound events;

b) cumulative sound exposure level (see ISO 1996-1);

c) summary of flight operations such as total number of departures and approaches.

It is optional to include the number of events that occur during the specified daytime, evening and night time periods.

7.2.5 Period summaries

Annual period summaries are required, but periods of three months, six months, and longer are optional. There are no mandated data for these reports, but they should follow the format of the monthly event summaries.

7.3 Environmental reports

Environmental reports are produced at various intervals and describe the total and/or the residual sound as measured by the sound monitor in statistical terms. No format, descriptor or information are required, as these are usually determined locally.

As a minimum, each environmental report should provide the level of the background sound (see 3.13.4) plus the time-average sound pressure level for each reporting period.

8 Instruction manual

As a minimum, the instruction manual for a sound-monitoring system shall contain the information listed below, for each sound monitor and where appropriate for several sound monitors working together as a system.

For class 1 sound level meters and equivalent instruments, all requirements concerning the instruction manual according to IEC 61672-1 shall be satisfied.

In the instruction manual, in addition to the data required by IEC 61672-1, the following data shall be provided:

a) the method for manually checking the acoustical calibration of the sound monitor;

b) the method for automatic signal-sensitivity verification of the sound monitor;

c) the method used for aircraft sound event detection and classification, and instructions on how to set the appropriate parameters;

d) the time intervals used to determine the short term equivalent continuous sound pressure levels;

e) the sampling intervals for $L_{p,\mathrm{AS}}(t)$ or the method used to calculate $L_{p,\mathrm{AS}}(t)$;

f) the level range used to calculate $L_{E,\mathrm{A}}$ (e.g. $L_{p,\mathrm{AS,max}}$ −10 dB, all levels above threshold level);

g) the method of error checking employed for transmission of data;

h) the A-weighted sound pressure level indication caused by wind at a steady speed of 10 m/s with the sound monitor assembled as recommended by the manufacturer or supplier;

i) any maintenance schedule required to ensure freedom from corrosion and the ingress of moisture;

j) the data storage capability of the monitoring system;

k) details of any computations for descriptors other than sound exposure or sound exposure level;

l) details of any computation to provide additional data as described in Clause 7;

m) if available, the method of treatment of any data for correlation of aircraft sound events and flight data;

n) if non-acoustical data are available and if the event identification is undertaken, the treatment of “unidentified events”.

Annex A
(informative)

Selection of sites for sound monitors

A.1 General

The sound-monitoring site is critical in obtaining useful sound data with minimal uncertainty. Because the requirements for sound data at particular sites may vary considerably, the engineering guidelines for placing sound monitors may also differ considerably. The selection of sound-monitoring sites should be carefully considered early in the development of a sound-monitoring plan, once the objectives for the sound monitors have been clearly identified. In order to analyse to what extent a proposed site may influence the uncertainty of the results of aircraft sound measurements at that site, it is necessary to examine carefully the relation between the residual sound and the maximum sound pressure level produced by the quietest aircraft type to be measured. For measurements uncontaminated by residual sound, the level difference should exceed 15 dB. At sites where such a difference is not achievable, additional measurement uncertainty is introduced.

A.2 Process of sound-monitoring site selection

The selection of sound monitor sites is usually a two-stage process. The first stage, for a generic sound-monitoring site, involves consideration of the sound-monitoring objectives, which might include the following:

a) to obtain reliable sound information in specific sound-sensitive community areas;

b) to obtain reliable information on the sound pressure levels at the particular site produced by different types of aircraft and operations for sound regulatory (sound limit) purposes, sound budget analyses, etc. and/or to monitor compliance with periodic sound exposure level requirements;

c) to obtain sound information to monitor aircraft departure or approach flight paths and to determine runway and flight path utilization;

d) to meet sound-monitoring system technical considerations, particularly the need to obtain sound information from more than one sound monitor under important departure or arrival paths for the separation of aircraft sound signals from other sounds in the community in the vicinity of the airport.

The second stage of the site selection process is the selection of specific sound-monitoring sites within the general area. This is based upon practical and other considerations such as:

- interference from other sound sources (road traffic, industry, wildlife, leisure activities etc.);
- if fixed telephone lines and power supplies are required, ease of access to utilities;
- terrain and building obstructions;
- ease and cost of obtaining site access and approvals (sites on private property may require payments of rent or easements; sites on publicly owned land such as parks may be less costly for public agencies, but obtaining formal approvals may be difficult and/or time consuming);
- sound monitor security considerations (vandalism, theft, and damage by animals);
- the likely uncertainty of the measurements.

A.3 Method to determine acoustically suitable sound-monitoring sites

A.3.1 General

In most cases, the measurement of the sound pressure is integrated over the duration of the aircraft event, like the single event level, $L_{E,\mathrm{A}}$, and indices based on $L_{E,\mathrm{A}}$ or $L_{p,\mathrm{eq},T}$. However, the determination of $L_{E,\mathrm{A}}$ by measurement requires the integration of the sound pressure in at least the range above the level "10 dB less than $L_{p,\mathrm{AS,max}}$" (see t_{max} in Figure 5). Further, for an acoustically reliable measurement, the aircraft event should be clearly distinguishable from residual sound, i.e. the difference between the level of the background sound and the sound level at the onset of a measurement should be at least 5 dB. Therefore, sound monitors should only be installed at sites where the maximum sound pressure levels, $L_{p,\ \mathrm{AS,\ max}}$, of aircraft events of interest are at least 15 dB greater than the level of the average residual sound.

The AS-weighted sound pressure level, $L_{p,\mathrm{AS}}(t)$, is used as an example in this annex; the A-weighted short term equivalent continuous sound pressure level, $L_{p,\mathrm{A,eq,1\ s}}$, can be used as its equivalent. This remark concerns the maxima, the measured levels and the exceedance levels.

For monitoring aircraft operations on a specific flight path, the area suitable for sound monitors may be determined by the following procedure.

a) There is always a certain percentage of quiet aircraft that the sound monitors do not detect. Therefore, on the basis of best-available data, the quietest aircraft (in operation at that airport, both currently and in the foreseeable future) for which reliable measurements are required should be identified, and the corresponding maximum sound pressure level, $L_{p,\mathrm{AS,max}}$, estimated.

b) At possible microphone positions, the average residual A-weighted sound pressure level should be estimated. For example, in rural areas this residual sound level might be 40 dB to 45 dB, increasing in urban areas up to 55 dB.

c) To avoid excessive ground effects, the elevation angle (the angle between the ground plane and the sound ray from the aircraft to the microphone) should be greater than 30°. This restricts the area close to the runway by two lines, originating at the lift-off point and intersecting the ellipse at the points where the aircraft is seen at an elevation angle of 30°. For lower elevation angles, the uncertainty of the measured sound levels increases.

A.3.2 Determination of acoustically suitable sound-monitoring sites

For reliable detection, 99 % of event maxima should be at least 15 dB above the residual sound level; the level of 15 dB above the residual sound level is referred to as L_{detect}.

The sound footprint for L_{detect} can be determined for a single flight of the quietest aircraft type. Usually, an aircraft noise calculation program would be used for this task. For a rough estimation, the contours may be determined manually with the steps outlined in a) to c). If there exist several climb profiles, the steepest profile is chosen because it usually produces lower sound pressure levels, and the least loud event that is measurable is needed.

a) For departure, the aircraft may reduce power after initial departure to "climb" conditions. For the aircraft in "climb" condition, determine the maximum sound pressure level, $L_{p,\mathrm{AS,max}}$, at a specified distance, e.g. at 305 m. Then estimate the distance, d_{max}, from the aircraft where the aircraft sound pressure level is L_{detect}. A doubling of distance may reduce the sound pressure level by 7 dB to 9 dB (6 dB due to spherical spreading plus air absorption). Alternatively, the distance, d_{max}, may be estimated directly from noise-power-distance (NPD) tables associated with aircraft noise calculation programs.

b) Using an average profile with a high rate of climb, determine the horizontal distance, x_{max}, flown by the aircraft to reach an altitude equal to d_{max}. The distance, x, is measured from the typical lift-off point on the runway.

c) For an average, straight departure, the area where sound pressure levels exceed L_{detect} is now defined by an ellipse in the following way: when the aircraft is close to the ground, the boundary of the area is d_{max} to either side of the runway. Along the flight path, the area narrows (as the aircraft climbs) to reach the tip of the ellipse at the distance x_{max}. (Geometrically, this is a cylinder of radius d_{max} around the flight path, which is intersected by the ground plane.)

For examples of determining the sound footprint, see A.3.3.

For microphone positions under curved flight paths, similar estimates may be used, looking at maximum allowable distance, d_{max}, from the curved flight paths, taking into account, if necessary, the greater spreading of flight paths in curved sectors.

Before making a definitive selection of any sound-monitoring site, some sound levels should be measured to assess the relation between residual sound and aircraft sound with respect to microphone-to-flight-path distances and maximum sound levels.

It may be necessary to install a sound monitor in an acoustically unfavourable area with the goal to demonstrate that there is usually little aircraft sound at the location. Such a sound monitor misses most aircraft events, but detects the exceptions that fly close to the microphone.

A.3.3 Examples

A.3.3.1 Example for departure

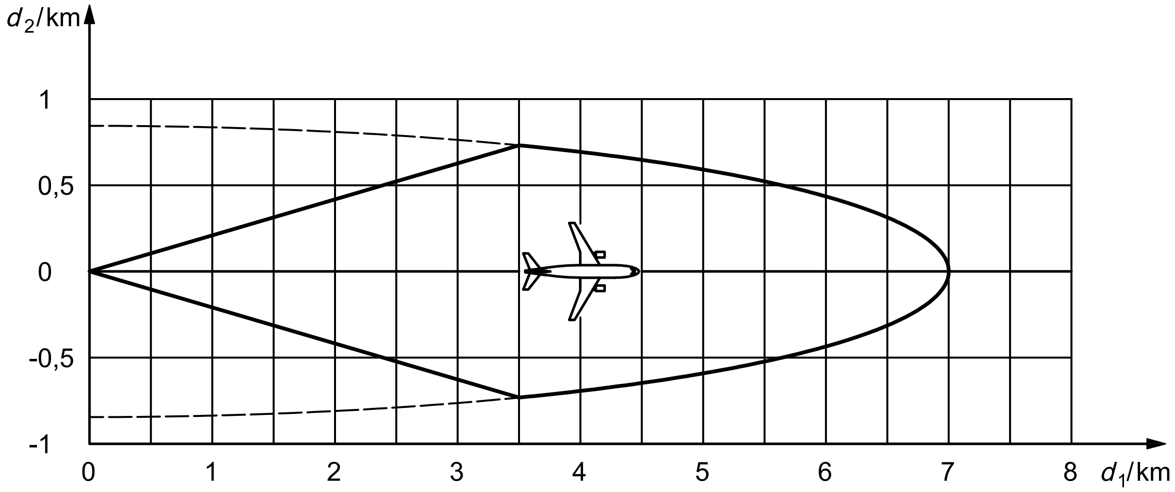
Assume that, at an airport, the sound produced by aircraft of a certain type requires measurement. Assuming a residual sound pressure level, $L_{p,\text{AS},95,T}$, of 55 dB, the required minimum L_{detect} is 70 dB. For the purpose of this estimation, the details of initial departure power and steeper profile may be ignored. It may be assumed that this particular aircraft type climbs at a constant rate out to an altitude of 2 500 m at a distance of 22 km from the airport.

Using an aircraft noise calculation program, it is estimated that a sound pressure level of 70 dB is heard at a distance, d_{max}, of 800 m. With the assumed rate of climb, 800 m altitude is reached at $H_{\text{max}} = 7$ km from lift-off. The possible area for reliable monitoring is thus the ellipse with the half-axes 0,8 km and 7 km. Up to about a distance of 3,5 km the area is further restricted by excluding sound incidences at elevation angles relative to the ground of less than 30°; the resulting area is as shown in Figure A.1.

A.3.3.2 Example for approach

The same procedures apply for landing approaches. Because the angle of descent is typically 3° for instrument landing system (ILS) approaches, the area for possible microphone positions is rather narrow.

At a given slant distance, approaching aircraft are generally quieter than departing ones. For the same situation of the particular aircraft type considered in A.3.3.1, the maximum lateral distance is now reduced to 400 m where the sound pressure level reaches 70 dB. Assuming a 3° ILS angle of descent, this lateral distance translates to a distance of 7,6 km from the touch-down point. Again with the restriction of excluding sound incidence angles relative to the ground of less than 30°, the resulting area is as shown in Figure A.2.

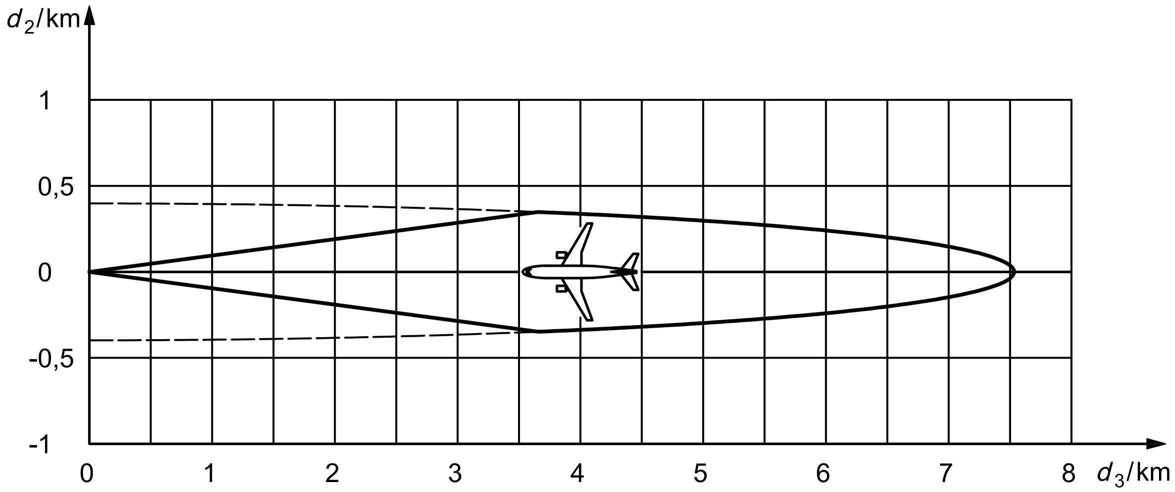


Key

d_1 distance from lift-off point

d_2 distance to side of flight path

Figure A.1 — Example for the estimation of microphone positions for reliable event detection (Departure of a particular aircraft, $L_{p,\mathrm{AS,max}}$ = 70 dB)



Key

d_3 distance to touch-down point

d_2 distance to side of flight path

Figure A.2 — Example for the estimation of microphone positions for reliable event detection (ILS-approach of a particular aircraft, $L_{p,\mathrm{AS,max}}$ = 70 dB)

Annex B
(informative)

Uncertainty of reported data

B.1 General

The accepted format for the expression of uncertainties associated with methods of measurement is given in ISO/IEC Guide 98-3. This format incorporates an uncertainty budget, in which all the various sources of uncertainty are identified and quantified, and from which the combined total uncertainty can be obtained. Definitive data to enable such a format to be adopted in the case of this International Standard were not available at the time of its preparation. However, an indication is given of the sources of uncertainty which are thought to be associated with the methods and equipment described. The general approach to calculation of uncertainties appropriate to this International Standard, in accordance with ISO/IEC Guide 98-3, is illustrated for information.

B.2 Expression for the calculation of the A-weighted sound exposure level for single aircraft sound events

Preliminary estimations show that the A-weighted sound exposure level of a single aircraft sound event i, $L_{E,\mathrm{A},i}$, according to this International Standard, is the sum of the following components, all expressed in decibels:

$$L_{E,\mathrm{A},i} = L_{E,\mathrm{A},i,\mathrm{meas}} + \delta_{\mathrm{slm}} + \delta_{\mathrm{residual}} \tag{B.1}$$

where

$L_{E,\mathrm{A},i,\mathrm{meas}}$ is the sound exposure level of an individual event, i, indicated by the sound monitor;

δ_{slm} is an input quantity to allow for any uncertainty in the measuring instrumentation (see B.3.1);

$\delta_{\mathrm{residual}}$ is an input quantity to allow for uncertainty due to the influences of residual sound (see B.3.2).

NOTE 1 A similar expression to that of Equation (B.1) applies with respect to maximum sound pressure levels determined for an individual aircraft sound event.

NOTE 2 Uncertainty in aircraft emissions and uncertainty in sound propagation are not included if the measurement goal is to measure total sound exposure for all aircraft.

NOTE 3 The terms included in Equation (B.1) to allow for uncertainties are those thought to be applicable from the state of knowledge at the time of preparation of this International Standard, but further research could reveal that there are others.

A probability distribution (normal, rectangular, etc.) is associated with each of the inputs to allow for uncertainties. Its expectation (mean value) is the best estimate for the value of the input and its standard deviation is a measure of the dispersion of values, termed uncertainty. It is presumed that the estimates of all of the δ input quantities for uncertainties given in Equation (B.1) are equal to zero. However, in any particular determination of a sound exposure level or maximum sound pressure level of a noise source under test, the uncertainties do not vanish and they contribute to the combined uncertainty associated with values of the sound exposure level or maximum sound pressure level.

B.3 Contribution to measurement uncertainty

B.3.1 Contributions due to the measuring instrumentation

The input quantity to allow for any uncertainty in the measuring instrumentation, δ_{slm}, depends at least on the sum of the following components, all expressed in decibels:

$$\delta_{\text{slm}} = \delta_{\text{mic}} + \delta_{\text{A}} + \delta_{\text{lin}} + \delta_{V} + \delta_{p} + \delta_{T} + \delta_{\text{RH}} + \delta_{\text{calref}} + \delta_{\text{calop}} \quad \text{(B.2)}$$

where

δ_{mic} is an input quantity to allow for influences of the directional response of the microphone, pre-amplifier, windscreen and all relevant accessories;

δ_{A} is an input quantity to allow for tolerances in the A-weighting;

δ_{lin} is an input quantity to allow for tolerances in the level linearity;

δ_{V} is an input quantity to allow for tolerances due to the influences of variable supply voltage;

δ_{p} is an input quantity to allow for influences of variations in ambient static air pressure;

δ_{T} is an input quantity to allow for influences of variations in air temperature;

δ_{RH} is an input quantity to allow for influences of variations in humidity;

δ_{calref} is an input quantity to allow for tolerances in the sound pressure level in the cavity of the sound calibrator under reference conditions;

δ_{calop} is an input quantity to allow for tolerances in the sound pressure level in the cavity of the sound calibrator under operational conditions.

NOTE 1 The input quantities included in Equation (B.2) allow for uncertainties considered to be applicable based on the knowledge at the time of preparation of this International Standard. In IEC 61672-1, additional tolerances are included for toneburst response and for the influence of alternating current and radio-frequency fields. These are assumed to have no influence on the measurement of the sound exposure level of the sound from an aircraft and are thus omitted. Further research could reveal another uncertainty analysis.

For estimation of standard uncertainties according to Equation (B.2), the tolerance limits specified in IEC 61672-1 for a class 1 sound level meter and in IEC 60942 for a class 1 sound calibrator are recommended. The tolerance limits from IEC 61672-1 should be used only when there is evidence from pattern evaluation tests and subsequent periodic tests of conformance to the requirements for class 1 performance. The tolerance limits in IEC 61672-1, corrected for the tolerances allowed for testing, are converted into uncertainties, simplified where necessary. It is assumed that 99 % of instrumentation (with a normal probability distribution) comply with the tolerances in IEC 61672-1, corrected for the tolerances allowed for testing. This gives a coverage factor k = 2,58.

In the general case of a microphone over a flat terrain and with a vertical microphone reference direction, the angle, θ, of sound incidence is usually less than 90° (corresponding to horizontal). The directional response limits vary with frequency and sound incidence angle and are specified in IEC 61672-1.

For the maximum level, $L_{p,\text{AS,max}}$, the angle between the reference direction of the microphone and the direction of the line perpendicular to the flight path (line s in Figure 3) may be used as an estimate for sound incidence angle, θ.

The influence of microphone directivity on sound measurement uncertainty can be kept low, if all angles, θ, for all aircraft fly-bys remain in a small range of variation for θ. Further, if the mean of the angle distribution differs considerably from the reference direction, the expectation value of δ_{mic} might be different from zero, i.e. a systematic correction should be applied.

For determination of sound exposure level, $L_{E,\mathrm{A}}$, $L_p(t)$ varies with the angle θ over a large range within the integration interval of $L_{E,\mathrm{A}}$. However, for the purpose of estimating the uncertainty of $L_{E,\mathrm{A}}$ as the uncertainty at levels close to $L_{p,\mathrm{AS,max}}$ are dominant, the same procedure as for $L_{p,\mathrm{AS,max}}$ may be used.

The shape of the A-weighted one-third octave spectrum, measured at the microphone, determines which frequency band contributes the dominant portion to an indication of sound level and consequently which frequency band has to be considered in estimating the uncertainty. The spectra for typical aircraft classes may be found, for example, in the Eurocontrol Aircraft Noise and Performance (ANP) database (Reference [6]). Typical spectra of jet powered aircraft at take-off engine power settings have a maximum between 250 Hz and 500 Hz. According to IEC 61672-1, the directional response limits for $\theta \leqslant 30°$ and $\theta \leqslant 90°$ are 1,3 dB and 1,8 dB, respectively. In this frequency range, the expanded uncertainty of measurement is 0,3 dB. In this case, assuming normal distribution with a coverage factor k = 2,58, the standard uncertainty is:

$$u_{\mathrm{mic}} = 1{,}0/2{,}58\ \mathrm{dB} = 0{,}39\ \mathrm{dB} \quad \text{for } \theta \leqslant 30° \qquad \text{(B.3)}$$

or

$$u_{\mathrm{mic}} = 1{,}5/2{,}58\ \mathrm{dB} = 0{,}58\ \mathrm{dB} \quad \text{for } \theta \leqslant 90° \qquad \text{(B.4)}$$

The tolerance in the frequency range from 50 Hz to 1,25 kHz remains below ± 1,5 dB (IEC 61672-1:2002, Table 2, class 1) and the expanded uncertainty of measurement is 0,5 dB.

$$u_{\mathrm{A}} = 1{,}0/2{,}58\ \mathrm{dB} = 0{,}39\ \mathrm{dB} \qquad \text{(B.5)}$$

The level linearity error shall not exceed ± 1,1 dB (IEC 61672-1:2002, 5.5.5, class 1) and the expanded uncertainty of measurement is 0,3 dB.

$$u_{\mathrm{lin}} = 0{,}8/2{,}58\ \mathrm{dB} = 0{,}31\ \mathrm{dB} \qquad \text{(B.6)}$$

The deviation of the displayed sound level shall not exceed ± 0,3 dB for changes in supply voltage (IEC 61672-1:2002, 5.20.2, class 1) and the expanded uncertainty of measurement is 0,2 dB.

$$u_V = 0{,}1/2{,}58\ \mathrm{dB} = 0{,}04\ \mathrm{dB} \qquad \text{(B.7)}$$

The deviation of the displayed sound pressure level shall not exceed ± 0,7 dB for variations in static air pressure between 850 hPa and 1 080 hPa (IEC 61672-1:2002, 6.2.1, class 1) and the expanded uncertainty of measurement is 0,3 dB.

$$u_p = 0{,}4/2{,}58\ \mathrm{dB} = 0{,}16\ \mathrm{dB} \qquad \text{(B.8)}$$

The deviation of the displayed sound level shall not exceed ± 0,8 dB for temperature variations between −10 °C and +50 °C (IEC 61672-1:2002, 6.3.3 and 6.4, class 1) and the expanded uncertainty of measurement is 0,3 dB.

$$u_T = 0{,}5/2{,}58\ \mathrm{dB} = 0{,}19\ \mathrm{dB} \qquad \text{(B.9)}$$

The deviation of the displayed sound level shall not exceed ± 0,8 dB for relative humidity between 25 % and 90 % (IEC 61672-1:2002, 6.4, class 1) and the expanded uncertainty of measurement is 0,3 dB.

$$u_{\mathrm{RH}} = 0{,}5/2{,}58\ \mathrm{dB} = 0{,}19\ \mathrm{dB} \qquad \text{(B.10)}$$

The tolerance limit is 0,4 dB for the sound pressure level in the cavity of a sound calibrator reference condition (IEC 60942, class 1).

$$u_{\mathrm{calref}} = 0{,}4/2{,}58\ \mathrm{dB} = 0{,}16\ \mathrm{dB} \qquad \text{(B.11)}$$

The tolerance limit is 0,4 dB for operating condition (IEC 60942, class 1).

$$u_{\text{calop}} = 0{,}4/2{,}58 \text{ dB} = 0{,}16 \text{ dB} \tag{B.12}$$

The combined standard uncertainty, u_{slm}, for the input quantity, δ_{slm}, is the square root sum of all u_i^2.

$$u_{\text{slm}} = 0{,}86 \text{ dB} \quad \text{for } \theta \leqslant 90° \tag{B.13}$$

$$u_{\text{slm}} = 0{,}74 \text{ dB} \quad \text{for } \theta \leqslant 30° \tag{B.14}$$

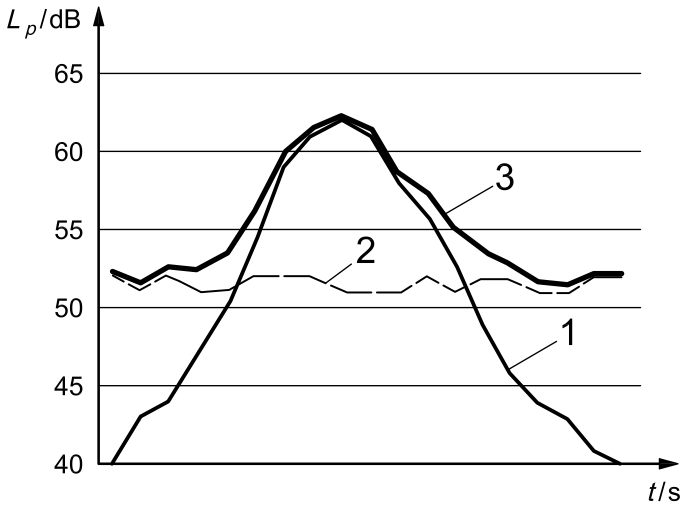
The largest contributions to this "worst case" expanded uncertainty come from the directional response of the microphone system, the A-weighting and level linearity. If it can be shown that the measurement chain operates with smaller deviations from the design goals specified in IEC 61672-1, then the resulting expanded uncertainty may be reduced accordingly.

NOTE 2 Sound-monitoring systems not designed to conform to the class 1 performance requirements of IEC 61672-1 are likely to produce measurements of aircraft sound with larger uncertainties than calculated above.

B.3.2 Contributions due to residual sound

The residual sound that is present during an aircraft event is included in the measurement and produces a level increase of ΔL_p relative to the continuous aircraft sound pressure level that would be measured in the absence of any residual sound.

Therefore the range of the residual sound and its variation should be considered. Figure B.1 illustrates a typical situation.



Key

t time

L_p sound level

1 aircraft

2 residual

3 measured

Figure B.1 — Example for the addition of residual and aircraft sound

A level correction, ΔL_p, to a measured aircraft sound level when the level of the residual sound is lower than the measured level by an amount ($L_{p,\text{meas}} - L_{p,\text{residual}}$) may be determined from Equation (B.15)

$$\Delta L_p = -10 \lg \left[1 - 10^{-0{,}1\left(L_{p,\text{meas}} - L_{p,\text{residual}}\right)} \right] \text{dB} \tag{B.15}$$

For examples, see Table B.1.

Table B.1 — Level corrections for three level differences
Corrections and differences in decibels (dB)

$L_{p,\text{meas}} - L_{p,\text{residual}}$	ΔL_p
15	0,1
10	0,5
6	1,3

To minimize the uncertainty due to contamination by residual sound, this International Standard recommends installing sound monitors only at sites where the aircraft event produces maximum sound pressure levels at least 15 dB greater than the A-weighted sound exposure level of the average residual sound (see Annex A).

NOTE 1 The level difference, ΔL_p, itself is uncertain, with contributions by the specific uncertainties of the directly measured quantities $L_{p,\text{meas}}$ and $L_{p,\text{residual}}$. Starting from Equation (B.17), δ_{residual}, the uncertainty of ΔL_p, can be calculated by application of ISO/IEC Guide 98-3. Relevant values for the standard uncertainty resulting from this origin have not yet been determined.

NOTE 2 The level difference, ΔL_p, applies directly to $L_{p,\text{AS,max}}$. For $L_{E,\text{A}}$, the level difference is slightly greater than ΔL_p because $L_{E,\text{A}}$ also includes sound pressure levels before and after $L_{p,\text{AS,max}}$ where the instantaneous level difference between aircraft sound and residual sound is less than for $L_{p,\text{AS,max}}$ resulting in a larger value for ΔL_p.

NOTE 3 In situations where the sound pressure level difference between measured sound and residual sound is small, several options are available, for example a) and b).

a) Level correction: From measurements before or after the aircraft event, the residual sound pressure level is determined. The $L_{E,\text{A}}$ for a constant residual sound exposure level over the duration of the aircraft event is determined and subtracted (on a mean-square sound pressure basis) from the $L_{E,\text{A}}$ of the aircraft event.

b) Elaborate instrumentation and signal processing capable of separating aircraft sound and residual sound based on specific characteristics may help reduce the influence of the residual sound.

NOTE 4 Event verification and identification based on additional non-acoustical information may exclude erroneously classified events where no aircraft sound was involved.

B.4 Combined and expanded uncertainty of measurement for single aircraft sound events

The combined uncertainty associated with the value of the A-weighted sound exposure level of a single aircraft sound event, $L_{E,\text{A},i}$, depends on the standard uncertainties of each of the input quantities, their respective probability distributions and sensitivity coefficients, c_i. The sensitivity coefficients are a measure of how the values of the A-weighted sound exposure level are affected by changes in the values of the respective input quantities. Mathematically, these coefficients are equal to the partial derivatives of the function $L_{E,\text{A},i}$ [Equation (B.1)] with respect to the relevant input quantities. The contributions of the respective input quantities to the overall uncertainty are then given by the products of the standard uncertainties and their associated sensitivity coefficients. For the case of negligible correlation between the input quantities, the combined standard uncertainty of the determination of the sound exposure level, $u(L_{E,\text{A}})$ is given by Equation (B.16):

$$u\left(L_{E,A}\right)=\sqrt{\sum_{i=1}^{2}\left(c_i u_i\right)^2} \qquad \text{(B.16)}$$

Table B.2 gives a numerical example of the type of information needed to derive the overall uncertainty.

Table B.2 — Uncertainty budget for determinations of sound exposure level

Quantity	Estimate dB	Standard uncertainty u_i dB	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $c_i u_i$ dB
$L_{E,\mathrm{A},i}$	$L_{E,\mathrm{A},i,\mathrm{meas}}$		normal	1	
δ_{slm}	0	0,74	normal	1	0,74
$\delta_{\mathrm{residual}}$	0	?	normal	1	

ISO/IEC Guide 98-3 requires an expanded uncertainty, U, to be specified, such that the interval $[L_E - U, L_E + U]$ covers, for example, 95 % of the values of L_E that might reasonably be attributed to the sound exposure level. To that end, a coverage factor, k, is used, such that $U = k\,u$. The coverage factor depends on the probability distribution associated with the measurement.

The combined expanded standard uncertainty of the determination of the sound exposure level, $U(L_E)$, is given by Equation (B.17):

$$U(L_{E,A}) = k\,u(L_{E,A}) \tag{B.17}$$

Assuming a normal distribution, a coverage factor, k, with a value of 2 has a coverage probability of 95 % and is used to report the expanded uncertainty of measurement.

B.5 Uncertainty of reported data for cumulative sound events

B.5.1 Contributions due to aircraft source emission

The level distribution of the aircraft source emission has a range ($L_{p,\mathrm{eq,AS},10,T} - L_{p,\mathrm{eq,AS},90,T}$) of up to about 2 dB (unpublished evaluation data from Reference [6]). As the fluctuations created along the propagation path between the aircraft and the receiver are typically about three times as large, the contribution due to the source itself can be neglected within the uncertainty budget except that significant directivity of the aircraft engine emission has to be considered.

The uncertainty of aircraft source emission, u_{ac}, may be assumed to remain constant for a given aircraft type, j (aircraft type designator, ATD, according to ICAO Doc. 8643 [3]), for an aircraft operation on a flight path.

$$u_{\mathrm{ac}} \approx C_j \tag{B.18}$$

The coefficient C depends on the aircraft types and aircraft operation (see Table B.1) and reflects the various engine types used with the same aircraft.

B.5.2 Contributions due to sound attenuation during propagation

B.5.2.1 General

The effects of propagation and ground effects at the receiver are interrelated, especially for ground-to-ground situations. For air-to-ground propagation, the two effects may be considered separately (curved propagation may slightly alter the angle of sound incidence, although this effect can be neglected in this context).

The sound exposure level measured at the microphone is composed of the direct sound wave and one (or several) sound wave(s) reflected at the ground (and other surfaces). These “ground effects” can be calculated (see ANSI/ASA S12.9-2 [2]). The ground effects may be considered as a frequency-dependent transfer function, which depends on height of microphone, angle of sound incidence and reflection properties of the ground at the place where reflection takes place (hard/soft; area of reflection described by the Fresnel zone, see Reference [4]). This frequency-dependent “ground effect transfer-function” indicates the modification of the sound pressure level at the microphone compared with the sound pressure level in an acoustic free field.

The measured sound exposure level depends on:

a) level and shape of the source spectrum and its variation with time;

b) spectral attenuation over the sound propagation paths in the air (i.e. the distance from aircraft to receiver);

c) “ground effect transfer-function”;

d) A-weighting.

The “ground effect transfer-function” is a succession of maxima and minima as a function of increasing frequency. For microphones at 6 m above ground and for sound angles of elevation greater than 30°, these effects are smoothed out in the A-weighted sound exposure level. For low microphone heights (e.g. 1,5 m) and for high angles of incidence relative to the reference direction of the microphone (e.g. 80°) the transfer function typically shows a distinct attenuation in the frequency range of 200 Hz to 300 Hz. Therefore, uncertainty increases for certain propeller-driven aircraft with dominant low frequency sounds, it increases with low microphone heights, and it increases with high angles of sound incidence relative to the microphone direction.

To keep uncertainties under control, this International Standard recommends: microphones at 6 m or higher over soft ground with no other reflecting surfaces; angles of elevation greater than 30°.

If the recommendations of Annex A for sufficiently high maximum sound levels of aircraft events are respected, then the shortest distances from aircraft to receiver are probably less than 1 km, which limits the influence of atmospheric absorption. For less ideal sound monitor positions and/or angles of elevation markedly less than 30°, uncertainty is usually greater.

The propagation of sound through the air influences the sound to be monitored in two ways.

— The general meteorological situation of wind and temperature layers has an influence on sound propagation, especially for ground-to-ground situations. Except for wind, general meteorological conditions change slowly compared to the duration of an aircraft event.

— Turbulence in the air produces short-term sound pressure level fluctuations during an aircraft event.

Thus the meteorological conditions modify the sound heard at the receiver. The receiver experiences the sound variations, and therefore these effects belong to the sound monitor under observation. They may produce large scatter in the data, but the uncertainty of each individual measurement is not affected. On the other hand, the short-term level fluctuations should be taken into account.

B.5.2.2 Air-to-ground sound propagation

The measured sound exposure level, $L_{E,\mathrm{A}}$, depends on the maximum AS-weighted sound pressure level, $L_{p,\mathrm{AS,max}}$, and the duration of the event. $L_{p,\mathrm{AS,max}}$ depends on the shortest distance between the aircraft and the receiver. This shortest distance (sometimes called “slant distance”) is a valuable descriptor to characterize measurement conditions.

For a sound measurement of aircraft elevation angles greater than 30° and in the absence of obstacles affecting air-to-ground propagation, the atmospheric effects of turbulence, wind and temperature become more pronounced with increasing “shortest distance”, producing increased scatter of measured levels, up to several decibels.

Similar sound events may be averaged to reduce the uncertainty of the mean value. For example, the resulting expanded uncertainty of sound monitor levels averaged over 100 similar aircraft events was reduced by a factor of 10 to some 0,3 dB to 0,5 dB.

These fast level fluctuations are the reason why aircraft sound is measured with time weighting S in order to reduce the influence of short-term level variations.

The uncertainty of sound attenuation during air-to-ground propagation, u_{att}, may be described by the empirical relationship

$$u_{att} = \left(\frac{r_0}{r}\right)^2 + \left(p_j\, r + q_j\right)^2 \qquad \text{(B.19)}$$

where

p_j, q_j are constants derived from specific investigations (see Table B.3);

r is the shortest distance from the aircraft to the receiver point ($r >$ dimension of aircraft);

r_0 = 750 m (see Reference [7]).

The constants p_j and q_j depend on the aircraft type (see Table B.3).

Table B.3 — Examples for coefficients to determine the uncertainty due to emissions and transmission (Reference [7])

Landing (final configuration)			
Type	C_j dB	p_j dB	q_j dB
A320	2,03	0,0003	1,2778
B73S	1,54	0,0003	1,2619
B7474	1,10	0,0003	1,2790
CL65	0,94	0,0003	1,3082
D328	1,60	0,0004	1,2489
DH8	4,02	0,0004	1,2679
MD11	1,14	0,0004	1,3015
MD83	1,34	0,0004	1,3171
RJ100	0,37	0,0003	1,2521
SF34	1,80	0,0006	1,2315

Departure (reduced power)			
Type	C_j dB	p_j dB	q_j dB
A320	1,07	0,0004	1,0671
B73S	1,48	0,0004	1,0389
B7474	1,76	0,0003	1,0685
CL65	1,46	0,0003	1,0699
D328	3,55	0,0003	1,0495
DH8	4,85	0,0002	1,0741
MD11	1,20	0,0003	1,0668
MD83	1,51	0,0003	1,0518
RJ100	1,53	0,0004	1,0754
SF34	3,20	0,0003	1,0534

B.5.2.3 Ground-to-ground propagation

For the situation where the source is close to the ground, e.g. for an aircraft on a runway, the measured sound levels may be heavily influenced by propagation close to the ground. Depending on the propagation conditions governed by wind and temperature profiles, sound may propagate on a curved path bent back to earth, surpassing barriers, which can result in sound pressure levels up to 10 dB above average levels. For other weather conditions, sound paths are bent upwards and a receiver position may lie in the “acoustic shadow” with level reductions of up to 10 dB or more. The level variations of ground-to-ground propagation depend on distance and local terrain (shielding effects) and on the statistics of typical temperature and wind profiles in the atmosphere. Special consideration should be given to temperature inversions at night (warm air above cold air), which favour sound propagation over barriers.

To prevent those large variations in reported data, recommendations of this International Standard exclude sound monitor sites for ground-to-ground propagation, i.e. with angles of elevation relative to the ground of less than 30°; for such locations uncertainty is usually higher.

An example is given in Reference [6]. The short term (about 1 min) uncertainty of L_{eq} is about 0,5 dB.

B.5.3 Contributions due to cumulation of sound event data

Post-processing may include aircraft identification and also averaging over flight paths (distribution within the flight corridor) of specific aircraft types in combination with different propagation situations and periods of the day over many days, months or a year. Here, uncertainties of (incorrect) aircraft identification, the handling of missed events and possible influences of “system down” conditions have to be considered.

NOTE 1 In this International Standard, all data from a continuously operating sound monitor are used for reporting. For results from mobile sound monitors, one might have to consider the appropriate duration of a measurement period to provide a reliable estimate of the yearly average sound pressure levels. This issue is addressed, for example, in ANSI/ASA S12.9-2 [2].

NOTE 2 A comparison between aircraft sound level calculation and measurement can illustrate the different sources of uncertainty. For calculations, the uncertainties of the measurement do not apply, and all variations of the “observed system” have to be modelled. The reliability of modelling determines the uncertainty of a calculation.

Long-term measurement results are influenced by the same parameters as described in Clause B.2, and in addition by the following effects.

The sound from a certain percentage of aircraft events remains less than the threshold level and is therefore not measured. If this is not compensated by substituting calculated estimations, the statistics of level distribution of the aircraft events becomes asymmetric: levels below the threshold level are cut off and the distribution shows only levels above that threshold level. If the average result is based only on the measured events, it tends to indicate greater sound levels, because the quiet events are not included. On the other hand, if the $L_{p,\text{eq}}$ is reported instead of sound exposure level, then this tends to be smaller because some aircraft sound is not included. In either event, adding the aircraft sound to the residual sound may result in large and incorrect increases to the residual sound pressure level.

As an example, the accumulated results for a specific period of day may be averaged over a series of days, a month or a year. Because sound exposure and not sound exposure levels are averaged, statistics using levels should be confined to level ranges of no more than 3 dB. This means that the estimation of uncertainty should be applied to groups of samples within a defined level range. When the sound exposure levels are normally distributed, which is usually the case, then log-normal statistics should be used with the distribution of sound exposures. Preferably the real distributions should be modelled adequately based on physical and procedural parameters by theoretical distribution types (e.g. Weibull).

Care should be taken that

a) all incorrect, incomplete or missing data are excluded from processing;

b) averages are only made over the time periods when the sound monitor is operating;

c) the set of all possible values of measurement is not biased by the necessary partial data exclusion.

Just as residual sound can bias the aircraft sound level upwards, “unidentified”, “missing” , and “corrupted” events, as well as sound 10 dB or more below the maximum for verified events, can all bias the aircraft sound downwards. This bias is system dependent and should be calculated or at least estimated on a case-by-case basis.

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