INTERNATIONAL STANDARD

ISO 5129

Third edition
2001-10-01

Acoustics — Measurement of sound pressure levels in the interior of aircraft during flight

Acoustique — Mesurage des niveaux de pression acoustique à l'intérieur des aéronefs en vol

Reference number
ISO 5129:2001(E)

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Printed in Switzerland

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

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 International Standard may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 5129 was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise*.

This third edition cancels and replaces the second edition (ISO 5129:1987), which has been technically revised.

Annex A of this International Standard is for information only.

Acoustics — Measurement of sound pressure levels in the interior of aircraft during flight

1 Scope

1.1 This International Standard specifies requirements for instruments and test procedures for the measurement and reporting of sound pressure levels at crew and passenger locations in the interior of aircraft under steady flight conditions. The sound pressure levels may be used to determine various quantities for describing the acoustical environment in the interior of the aircraft. The procedures are intended to ensure uniformity in test results and to provide the basis for determination of measurement uncertainties.

1.2 This International Standard provides electroacoustical performance specifications for a complete measurement system from a microphone to the readout device. Various individual components of a measurement system may be selected so long as the total measurement system conforms to the specifications of this International Standard.

1.3 The preferred measurement procedure involves the recording of sound pressure signals with subsequent analysis into one-third-octave band sound pressure levels. Direct measurements may be made of one-third-octave-band sound pressure levels.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 31-7, *Quantities and units — Part 7: Acoustics*[1)]

ISO 266, *Acoustics — Preferred frequencies*

IEC 60942, *Electroacoustics — Sound calibrators*

IEC 61183, *Random-incidence and diffuse-field calibration of sound level meters*

IEC 61260, *Electroacoustics — Octave-band and fractional-octave-band filters*

IEC 61672-1, *Electroacoustics — Sound level meters — Part 1: Specifications* [2)]

3 Terms and definitions

For the purposes of this International Standard, in addition to the terms and definitions given in ISO 31-7, the following definitions apply. Definitions of other relevant quantities are given in IEC 61672-1.

1) To be revised as ISO/IEC 80000-8.

2) To be published.

3.1
aircraft
any machine that can derive support in the atmosphere from reactions of the air other than the reactions of the air against the earth's surface

3.2
beats
periodic variations in amplitude that result from the superposition of two simple harmonic quantities of different frequencies f_1 and f_2

NOTE Beats involve the periodic increase and decrease of amplitude at the beat frequency $|(f_1 - f_2)|$.

3.3
crew station
location intended to be occupied or used only by aircraft crew during flight operations

3.4
crew sleeping quarters
enclosed compartment for crew rest or sleep

NOTE Crew sleeping quarters are also known as crew rest quarters, crew rest modules, or crew rest areas.

3.5
passenger compartment
any area intended to be occupied by passengers during flight

3.6
synchrophaser
device to control the rotational speed and phase of propellers on multi-engine aircraft

3.7
steady flight
conditions under which aircraft parameters that significantly affect interior sound pressure levels are controlled so as to yield reproducible results

4 Instruments

4.1 General

A complete sound measurement system is composed of a microphone system, data recording and data analysis devices, a sound pressure level display device, and a sound calibrator to establish the overall acoustical sensitivity of the system. A measurement system may include multi-channel instruments and shall conform at least to the applicable class 2 performance specifications of IEC 61672-1. A measurement system, including a microphone system according to 4.2, that utilizes an integrating-averaging sound level meter or a conventional sound level meter with exponential time weighting shall conform at least to the applicable class 2 specifications of IEC 61672-1. One-third-octave-band time-averaged sound pressure levels shall be determined with spectrum analysers that conform at least to the class 2 specifications of IEC 61260.

4.2 Microphone system

The microphone system shall conform to the applicable specifications of IEC 61672-1 for random-incidence sounds. Random-incidence response of the microphone system shall be verified by a procedure from IEC 61183.

NOTE A microphone system includes those components of a measurement system that produce an electrical signal in response to a sound pressure. The components generally include one or more microphones with preamplifiers and extension cables, and other devices as necessary such as windscreens.

4.3 Sound calibrator

The sound calibrator shall conform at least to the class 1C requirements of IEC 60942. The nominal frequency of the sinusoidal sound signal produced by the sound calibrator shall be in the range from 200 Hz to 1 250 Hz.

4.4 Verification of conformance

The performance of the instruments in a measurement system should be verified to conform to the applicable requirements of IEC 61672-1, IEC 60942 and IEC 61260 within a year before conducting a test in accordance with this International Standard.

5 Test procedures

5.1 Measurement procedures

5.1.1 Measurement locations

5.1.1.1 Passenger compartments

Sound pressure signals shall be measured at the typical head position of a seated passenger or flight attendant, with the passenger or attendant not present. The microphone shall be located on the seat centreline, with the axis vertical and pointed upwards, a distance of 0,15 m $\pm$ 0,025 m from the headrest and 0,65 m $\pm$ 0,05 m above the unoccupied seat cushion. The number and distribution of measurement locations in a passenger compartment will depend on the aircraft's seating arrangements and the specific test objectives. Measurement locations shall be chosen so as to provide a representative description of the acoustical environment in the passenger compartment.

5.1.1.2 Crew stations

Sound pressure signals shall be measured at typical head positions of the crew. At flight crew locations, the microphone shall be placed at a representative seated head height and within 0,1 m of the typical ear position where speech communication is normally received, with the flight crewmember present and seated. Measurements at a cabin-crew-standing location shall be made with the microphone 1,65 m $\pm$ 0,1 m above the floor, and with the crewmember not present. Measurements at cabin-crew-seated locations not in the passenger compartment shall be made in accordance with the specifications in 5.1.1.1. Retractable seats shall be in the occupied configuration.

5.1.1.3 Crew sleeping quarters

Sound pressure signals shall be measured at the resting position of the crewmember's head, with the crewmember not present. The microphone shall be placed a distance of 0,15 m $\pm$ 0,025 m above the mattress, blanket or headrest, as appropriate. If the head position is close to a wall, the microphone shall be not less than 0,15 m from that wall.

5.1.1.4 Microphone mounting

The microphone shall be held in a fixed location with a bracket or extension rod as appropriate to minimize interference and shielding effects, including those that are caused by an operator holding the microphone extension rod or support device. A windscreen shall be fitted around the microphone if airflow impinges on the microphone during a test. The insertion loss of the windscreen as a function of frequency and angle of sound incidence, in the absence of wind, shall be known from manufacturer's data or other experimental evidence.

5.1.2 Acoustical sensitivity and background electrical noise

5.1.2.1 Acoustical sensitivity

The overall acoustical sensitivity of the measurement system shall be determined, while on the ground, prior to, and after, the measurements of sound pressure levels in the aircraft interior. Determination shall be by means of the sound calibrator or by a combination of the sound calibrator and a sinusoidal electrical signal inserted through the electrical input facility in place of the microphone output. Additional checks of acoustical sensitivity may be made during a test. Appropriate adjustments shall be applied to the indicated sensitivity levels to account for the effects of differences between the prevailing atmospheric pressure and air temperature and the reference atmospheric pressure and air temperature specified in IEC 60942.

5.1.2.2 Background electrical noise

The background electrical noise of the measurement system shall be determined in one-third-octave bands with the microphone(s) placed in a low-level sound field. Background electrical noise shall be determined for level ranges used for data acquisition. When recorded, the duration of the recording time shall be at least 30 s.

5.1.3 Acoustical data acquisition

5.1.3.1 Data recordings

For each measurement, the duration of the recording shall be at least 30 s. The level-range-control settings of the recording system shall be monitored to ensure that signals are recorded near the optimum record level, avoiding overload of input stages. If beats are noted to be present, the recording time at a measurement location shall include at least four beat periods, with a minimum recording time of 30 s.

5.1.3.2 Direct measurements

An integrating-averaging sound level meter with a set of one-third-octave-band filters, or a spectrum analyser, is preferred for direct measurement of one-third-octave-band sound pressure levels. Averaging times shall be as specified in 6.1.

NOTE Time weighting S should be used if sound pressure levels are measured by a conventional sound level meter.

5.1.3.3 Crew sleeping quarters

Sound pressure signals shall be recorded for at least 30 s at locations noted in 5.1.1.3 and with minimal cabin and cockpit transient sounds (that is, no audible conversations, radio transmission, or transient operation of equipment). If measurement of transient sounds is required, sound pressure signals shall be recorded while the source of the transient sound is activated, for example, by flushing the toilet in a lavatory, opening and closing the door to a cockpit or lavatory, or operations in a galley. Five separate recordings of the sound pressure signal shall be made for each transient sound source.

5.2 Test conditions

5.2.1 Configuration of the aircraft interior

The interior of the aircraft shall be fully furnished with carpets, seats and curtains, and the configuration shall be noted. Factors that influence interior sound pressure levels, such as the location of partitions in the passenger compartments and the material used to cover the seats, shall be included in the description of the aircraft configuration. Seat backrests shall be set to their most upright position. The number of persons in the test aircraft shall be kept to the minimum required to conduct the tests. When feasible, no person shall be located so as to cause a significant effect on the sound field at a measurement location. No person shall be seated or standing within 1 m of the microphone, except at flight crew stations. The positions of all persons shall be noted.

5.2.2 Configuration of aircraft systems

Pressurization and air-conditioning systems shall be operating normally or in automatic mode. For aircraft not equipped with an environmental control system that has an automatic mode, the system shall be set to deliver 100 % of maximum design airflow. For unpressurized aircraft or environmental control systems that are designed to deliver 100 % airflow only in the event of an emergency, the airflow rate shall be representative of that for normal operating conditions. All individual passenger or crew air outlets shall be closed, except where required for normal operation. The public address system shall not be operating. Noise and vibration control systems shall be operating normally.

5.2.3 Crew sleeping quarters

Crew sleeping quarters shall be in a deployed position representative of normal use and unoccupied, with the access door closed, mattresses and blankets installed, as appropriate, and the public address system turned off. The aircraft environmental control system shall be operating normally to maintain a comfortable air temperature in the sleeping quarters. Diffusers for the environmental control system shall be set according to the design airflow requirements for crew sleeping quarters. Bunks shall be unoccupied.

5.3 Aircraft flight conditions

5.3.1 General

Aircraft flight conditions shall be those for steady flight, with aircraft Mach number or indicated airspeed, or both, and engine power settings or shaft rotational speeds, or both, stabilized to specified values within specified tolerance limits.

5.3.2 Flight condition data

The following data shall be recorded at appropriate intervals while sound pressure signals are measured:

a) aircraft altitude or pressure altitude, as appropriate;

b) aircraft Mach number or indicated airspeed, or both;

c) engine power settings (for example, engine shaft rotational speed or pressure ratio and synchronizer setting, or propeller rotational speed and engine torque and synchrophaser setting);

d) rotorcraft main rotor and tail rotor rotational speeds;

e) nominal position of the aircraft center of gravity;

f) nominal quantity of fuel in the fuel tanks, as total fuel weight or as a percentage of maximum fuel load;

g) external ambient static air temperature (if static temperature is not given directly by aircraft instruments, record data appropriate for later calculation of static temperature);

h) cabin pressure differential (inside minus outside) or cabin pressure and nominal cabin air temperature;

i) environmental control system setting.

6 Data processing

6.1 Averaging time

The averaging time for determining one-third-octave-band sound pressure levels shall be at least 16 s. If beats are noted to be present, the averaging time shall include at least three beat periods with a minimum averaging time of 16 s.

6.2 Sound spectra

One-third-octave-band filters shall be used to determine the spectrum of the sound in an aircraft. Octave-band sound pressure levels shall be determined from ten times the logarithm to the base 10 of the ratio of the sum of time-mean-square sound pressures in the three contiguous bands centred around the midband frequency of an octave band to the square of the reference sound pressure. The nominal midband frequencies of the filters shall cover the range appropriate for the aircraft and shall be identified by the preferred frequencies of ISO 266. As a minimum, the range shall be from 50 Hz to 10 kHz. For helicopters, the low frequency range shall extend at least to the one-third-octave midband frequency at 16 Hz.

NOTE The method of IEC 61400-11 [1] may be considered for evaluating the audibility of discrete-frequency components that can be present in a sound spectrum.

6.3 Adjustment for frequency response

All one-third-octave-band sound pressure levels shall be adjusted, as required, for deviations of the random-incidence frequency response of the complete measurement system from a response that is independent of frequency. Adjustments for the effect of windscreen insertion loss shall be made when these devices are used in measurements of sound pressure levels.

6.4 Background noise correction

If required, the contribution of electrical noise to an indicated one-third-octave-band sound pressure level shall be removed from those indicated sound pressure levels that are 3 dB, or more, greater than the corresponding level of the background electrical noise. One-third-octave-band sound pressure levels that are not more than 3 dB greater than the corresponding level of background electrical noise shall not be reported and the test report shall indicate the reason.

The test report may provide the sound pressure levels that were contaminated by background electrical noise from the measuring instruments. Any contaminated band sound pressure levels should be clearly marked and the corresponding spectrum of the contaminating background electrical noise reported.

6.5 Wideband sound pressure levels and frequency-weighted sound pressure levels

“Wideband” or “overall” sound pressure levels shall be determined from ten times the logarithm to the base 10 of the ratio of the sum, over the specified frequency range, of the time-mean-square one-third-octave-band sound pressures to the square of the reference sound pressure. Frequency-weighted sound pressure levels (for example, A-weighted sound pressure levels) shall be obtained in a similar manner after adding the standard frequency weighting from IEC 61672-1 to the one-third-octave-band sound pressure levels.

6.6 Transient sounds

The maximum F-time-weighted and A-frequency-weighted sound pressure level during the recording interval shall be used to characterize a measurement of a transient sound. Time-weighting F and frequency-weighting A shall be as specified in IEC 61672-1.

6.7 Measurement uncertainties

Annex A describes a method that may be used to estimate the expanded uncertainties of measurement for the levels of acoustical quantities that characterize the acoustical environment in the interior of an aircraft.

7 Data to be reported

7.1 Test report

A test report shall be prepared to document the measurements of aircraft-interior sound pressure levels. The test report shall include the following information, as appropriate.

a) A reference to this International Standard.

b) A description of the test aircraft and its propulsion system, including the type of propulsion, serial numbers, and aircraft takeoff gross weight.

c) A description of the instruments used for recording and spectral analysis and their calibrations, including the manufacturer's model and serial numbers; the location of the recording equipment in the airplane shall also be included.

d) A description of the flight conditions and engine, propeller or rotor operating conditions specified in 5.3.

e) The operating conditions for audible sound sources not covered by the items in d).

f) The nominal position of the aircraft centre of gravity at the time of measuring sound pressure signals in the aircraft.

g) The nominal fuel load at the time of measuring sound pressure signals in the aircraft.

h) A description of special noise and vibration control systems, if installed, including the setting of propeller synchrophaser or engine rotor synchronizer.

i) A description of the configuration of the passenger compartment, crew sleeping quarters, crew stations and galleys, with plan and cross-section views.

j) A description of the locations of persons seated or standing in the various areas during the measurements.

k) A description of the locations where sound pressure levels were measured, with notations in the plan and cross-section views of appropriate measurement locations.

l) A description of the test procedures.

m) If noted to be present, the presence and sources of discrete-frequency and transient sounds and beats.

n) Tabulation, in printed or electronic form, of all measured one-third-octave-band sound pressure levels and calculated octave-band sound pressure levels. Supplemental graphs may be provided for the sound pressure level spectra at appropriate measurement locations.

o) For transient sounds, tabulation, in printed or electronic form, of the corresponding maximum F-time-weighted and A-frequency-weighted sound levels.

p) Quantities (for example, speech interference levels, A-weighted sound pressure levels, and wideband sound pressure levels) calculated from the measured frequency-band time-averaged sound pressure levels. When A-weighted or wideband time-averaged sound pressure levels are reported, the frequency ranges of the corresponding one-third-octave bands shall be reported. When speech interference levels are calculated, the midband frequencies of the corresponding octave-band sound pressure levels shall be reported. It is recommended that the test report provide estimates of the expanded uncertainty of measurement for quantities that characterize the acoustical environment in the interior of the aircraft.

7.2 Reported sound pressure levels

All reported sound pressure levels and derived acoustical quantities shall be relative to a reference sound pressure of 20 μPa. If sound pressure levels are rounded to the nearest integer, half decibels shall be rounded to the next higher integer.

Annex A
(informative)

Measurement uncertainty

A.1 General

A.1.1 An uncertainty is always associated with a measurement. A general procedure for determining the uncertainty of a measurement is provided in reference [2]. Metrological terms are defined in reference [3].

A.1.2 The combined standard deviation of the uncertainty of a measured sound pressure level is determined from the square root of the sum of the variances attributed to all relevant contributions to the uncertainty. The combined uncertainty of a summary indicator of the acoustical environment is not the same as the combined uncertainty of the corresponding one-third-octave-band or octave-band sound pressure levels. The square root of the sum of all applicable variances is the combined standard deviation of the uncertainties. The positive square root of an individual variance is the standard deviation of the uncertainties associated with that contribution.

A.1.3 In accordance with the convention adopted in reference [2] and accepted by Technical Committee ISO/TC 43 for International Standards in acoustics, the uncertainty of measurement should have a level of confidence of 95 %. The two-sided interval around a measured result for a level of confidence of 95 % represents the interval that would encompass the results of several replications of the measurement. The interval is the expanded uncertainty of measurement. Multiplying the calculated combined standard deviation by a “coverage factor” yields the expanded uncertainty of measurement at a given location.

A.1.4 If the contributions to the individual variances, in a determination of a combined standard deviation, are normally distributed, then a coverage factor of 2 approximates to a level of confidence of 95 %. For some measurements, a coverage factor different from 2 may be required to achieve a level of confidence of 95 %.

A.2 Application

A.2.1 For a given model of an aircraft, interior arrangement and propulsion system, there rarely is more than one opportunity to measure interior sound pressure levels in accordance with the requirements of this International Standard.

A.2.2 There are at least four sources of individual contributions to the combined standard deviation of uncertainty of a measurement of the sound in an aircraft. With general letter symbol s for an estimate of a standard deviation, the individual sources include the following:

— s_I for the standard deviation associated with the acoustical measuring instruments and representing deviations from design goals;

— s_P for the standard deviation associated with the characteristics of the sound field that is present at a measurement location and with the reproducibility of measurements at a particular location (see 5.1.1); if the sound field contains discrete-frequency components, standing waves can be present and their effect should be considered when evaluating the standard deviation (see 5.1.3);

— s_F for the standard deviation associated with the effect of the reproducibility of the flight conditions and the influence of turbulence, in the mass of air through which the aircraft is flown, on the measured sound pressure levels; the flight condition includes the setting of the environmental control system, airspeed, altitude and engine power settings (see 5.2 and 5.3); and

— s_C for the standard deviation associated with the effects of variations in the construction of the aircraft and variations in the configuration from one aircraft to another of a given model.

The individual standard deviations might not be mutually independent. Appropriate values for the standard deviations also can depend on the quantity chosen to indicate the acoustical environment in the aircraft and the spectrum of the sound at the measurement location.

NOTE ISO 9921-1 [4] describes speech interference levels.

A.2.3 A general expression for calculating an expanded uncertainty of measurement, U, is as follows under the assumption that the above four individual standard deviations are all that apply to a given measurement situation:

$$U = \pm\, k \sqrt{s_{\mathrm{I}}^2 + s_{\mathrm{P}}^2 + s_{\mathrm{F}}^2 + s_{\mathrm{C}}^2} \quad \text{(A.1)}$$

The coverage factor to achieve the confidence level of 95 % is represented in equation (A.1) by symbol k. The individual standard deviations and the expanded combined uncertainty of measurement are in decibels for indicators of the acoustical environment in an aircraft. The square of a standard deviation is the variance associated with the contribution.

A.2.4 Of the individual contributions to the combined standard deviation in equation (A.1), the standard deviation associated with the measuring instruments is likely to be the smallest. For the measuring instruments, the standard deviation may be minimized by calibration and application of the adjustments described in this International Standard. The standard deviation for the measuring instruments is likely to be less than the tolerance limits allowed for design and manufacturing in the IEC standards referenced in this International Standard.

A.2.5 The procedure in reference [2] recognizes two methods for evaluating uncertainties: type A and type B. Type A uncertainties are obtained from a statistical analysis of a series of observations. Type B uncertainties are evaluated based on best available information, relevant experience, and engineering judgment. Reference [2] provides guidance for the evaluation of type A and type B uncertainties.

A.2.6 The contributions in equation (A.1) to the combined uncertainty of a measurement should be evaluated as type B uncertainties. No universally applicable method can be recommended for evaluating the type B uncertainties. For a given measurement, assignment of appropriate uncertainties depends on detailed knowledge of the influence of the sound field, flight conditions and aircraft configuration.

Bibliography

[1] IEC 61400-11, *Wind turbine generator systems — Part 11: Acoustic noise measurement techniques*

[2] *Guide to the expression of uncertainty in measurement*. BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML, 1995 (ISBN 92-67-10188-9)

[3] *International vocabulary of basic and general terms in metrology*. BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML, 1993 (ISBN 92-67-01075-1)

[4] ISO 9921-1, *Ergonomic assessment of speech communication — Part 1: Speech interference level and communication distances for persons with normal hearing capacity in direct communication (SIL method)*

ICS 17.140.30; 49.020

Price based on 10 pages