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Acoustics — Determination of sound power radiated into a duct by fans and other air-moving devices — In-duct method

Acoustique — Détermination de la puissance acoustique rayonnée dans un conduit par des ventilateurs et d'autres systèmes de ventilation — Méthode en conduit

Reference number
ISO 5136:2003(E)

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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 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 5136 was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise*.

This second edition cancels and replaces the first edition (ISO 5136:1990), which has been technically revised.

Introduction

This International Standard describes a procedure for the measurement of sound pressure levels in the inlet or outlet ducts of a fan and a method to use these sound pressure levels to calculate the sound power levels radiated by the fan to the duct system.

Annex A lists values of coefficients for the determination of the combined mean flow velocity and modal correction. Annex B specifies two procedures for the determination of the signal-to-noise ratio of sound versus turbulence. A computational procedure for the calculation of the A-weighted sound power level from one-third-octave band levels is given in Annex C. Annex D shows an example of the calculation of the combined mean flow velocity and modal correction.

The sound power radiated into a duct by a fan or other air-moving device depends to some extent on the type of duct, characterized by its acoustical impedance. For a measurement method, the test duct has, therefore, to be clearly specified. In this International Standard, the test duct is of circular cross-section and terminated anechoically. Details of typical anechoic terminations are given in Annex E. The sound power obtained under these special conditions is a representative value for actual applications, as the anechoic termination forms an impedance about midway between the higher and lower impedances found in practice. The sound power radiated in actual applications can, in theory, be estimated from data on air-moving devices and duct impedances. Since this information is at present incomplete, these effects are not usually considered in acoustical calculations.

In order to suppress the turbulent pressure fluctuations at the microphone, the use of a long cylindrical windscreen (“sampling tube”) is preferred. The microphone, with the sampling tube, is mounted at a radial position such that the sound pressure is well related to the sound power by the plane wave formula to an acceptable extent, even in the frequency range in which higher-order acoustic modes are possible.

The uncertainty of measurement (see Clause 4) is given in terms of the standard deviation to be expected if the measurements were repeated in many different laboratories.

The procedures for measuring the operating conditions (performance measurements) are not specified in detail in this International Standard. The operating conditions are specified in ISO 5801.

This International Standard is one of a series specifying different methods for determining the sound power levels of fans and other air-moving devices.

In general, the sound powers radiated from a fan inlet or outlet into free space and into a duct are different because of the reflection of sound energy at the fan inlet or outlet plane when there is no connected duct. The in-duct method according to this International Standard is suitable for determining the sound power radiated into a duct by a fan inlet or outlet. The sound power radiated into free space by a fan inlet or outlet should be determined using the a reverberation room method (ISO 3741, ISO 3743), a free-field method (ISO 3744, ISO 3745, ISO 3746) or a sound intensity method (ISO 9614).

Acoustics — Determination of sound power radiated into a duct by fans and other air-moving devices — In-duct method

1 Scope

1.1 General

This International Standard specifies a method for testing ducted fans and other air-moving devices to determine the sound power radiated into an anechoically terminated duct on the inlet and/or outlet side of the equipment.

NOTE 1 For the sake of brevity, wherever the term “fan” occurs in the text, it means “fan or other air-moving device”.

The method is applicable to fans which emit steady, broad-band, narrow-band and discrete-frequency sound and to air temperatures between – 50 °C and + 70 °C. The test duct diameter range is from 0,15 m to 2 m. Test methods for small ($d < 0{,}15$ m) and large ($d > 2$ m) test ducts are described in the informative Annexes H and I, respectively.

The maximum mean flow velocity at the microphone head for which the method is suitable depends on the type of microphone shield used, and is as follows:

- foam ball 15 m/s;
- nose cone 20 m/s;
- sampling tube 40 m/s.

Above these values the suppression of turbulent pressure fluctuations by the microphone shield (see 3.9) may be insufficient.

It is expected that sound power tests will be conducted in conjunction with airflow performance tests in accordance with ISO 5801. The ducting arrangement will therefore normally incorporate a “star” type flow straightener on the outlet side of the fan which will minimize swirl (see 7.3). Where it is permissible to delete the straightener as, for example, with large fans to installation category C according to ISO 5801:1997, the method is limited to a swirl angle of 15°. (An example of a method for determining the angle of swirl is given in Annex J.)

NOTE 2 The installation categories defined in ISO 5801 imply that the fan is either ducted on the outlet side only (category B), on the inlet side only (category C) or on both sides (category D).

1.2 Types of sound source

The method described in this International Standard is applicable to a sound source in which a fan is connected to ducts on at least one side. It is also applicable to other fan/attenuator combinations or equipment incorporating fans which can be considered as “black boxes”.

Examples of fans and other equipment covered by this International Standard are

- ducted centrifugal fans,
- ducted axial flow fans,

- ducted mixed-flow fans,
- ducted air-handling units,
- ducted dust-collection units,
- ducted air-conditioning units, and
- ducted furnaces.

This International Standard is also applicable to other aerodynamic sources such as boxes, dampers and throttle devices provided that a quiet air flow delivered by an auxiliary fan is available, and the signal-to-noise ratio of sound pressures to turbulent pressure fluctuations in the test duct is at least 6 dB (see 7.2.1).

An alternative method to determine the sound power level of the flow-generated noise of such aerodynamic sound sources, which does not require the measurement of sound pressure in a flow environment, is described in ISO 7235. The method was originally devised for the determination of the flow noise level of ducted silencers. The sound power is determined in a reverberation room connected to the test duct via a transition element.

In the case of ducted fans with closely coupled attenuators, the signal-to-noise ratio of sound pressures to turbulent pressures may be insufficient when using the in-duct method. Therefore the method described in ISO 7235 is recommended for such fan/attenuator combinations.

This International Standard is not applicable to non-ducted fans or equipment.

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 266, *Acoustics — Preferred frequencies*

ISO 5801:1997, *Industrial fans — Performance testing using standardized airways*

IEC 60651:2001, *Sound level meters*

IEC 60942:1997, *Electroacoustics — Sound calibrators*

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

3 Terms, definitions and symbols

For the purpose of this document, the following terms and definitions apply. The symbols are given in Table 1.

3.1
fan inlet area
S_{f1}
surface plane bounded by the upstream extremity of the fan

NOTE 1 The inlet area is, by convention, taken as the gross area in the inlet plane inside the casing. No deduction is made for motors, fairings or other obstructions.

NOTE 2 Where motors, fairings or other obstructions extend beyond an inlet or outlet flange at which the performance for ducted installation is to be determined, the casing should be extended by a duct of the same size and shape as the inlet or outlet and of sufficient length to cover the obstruction. The test airway dimensions should be measured from the plane through the outermost extension of the obstruction as if this were the plane of the inlet or outlet flange.

NOTE 3 The fan inlet area is expressed in square metres (m^2).

NOTE 4 Adapted from ISO 5801:1997.

3.2
fan outlet area

S_{f2}

surface plane bounded by the downstream extremity of the fan

NOTE 1 The outlet area is, by convention, taken as the gross area in the outlet plane inside the casing. No deduction is made for motors, fairings or other obstructions.

NOTE 2 Some free-outlet fans without casings have no well-defined outlet area. For the purpose of determining the fan's dynamic pressure, a nominal area may then be defined and stated, e.g. the area within the ring of a propeller wall fan or the circumferential outlet area of an open-running centrifugal impeller. The corresponding fan dynamic pressure and fan pressure will also be nominal and should be so described.

NOTE 3 The fan outlet area is expressed in square metres (m^2).

NOTE 4 Adapted from ISO 5801:1997.

3.3
ducts

any of the airways defined in 3.3.1, 3.3.2 and 3.3.3

3.3.1
test duct

duct in which the fan sound power is measured

NOTE The test duct has an anechoic termination.

3.3.2
terminating duct

duct opposite to the test duct, if both sides of the fan are ducted

NOTE The terminating duct has an anechoic termination.

3.3.3
intermediate duct

duct fitted on the intake side and on the discharge side of the fan to ensure desired flow conditions

NOTE The intermediate duct connects to the test duct or the terminating duct, if necessary by a transition section (see Figure 7).

3.4
measurement plane

radial plane in the test duct in which the microphone diaphragm is located

3.5
sound pressure level

L_p

$$L_p = 10 \lg \frac{p^2}{p_0^2} \text{ dB} \tag{1}$$

where p is the root mean square value of the sound pressure and the reference sound pressure p_0 is equal to 20 µPa

NOTE 1 The width of a restricted frequency band should be indicated, for example, octave-band sound pressure level, one-third-octave-band sound pressure level.

NOTE 2 L_{p1}, L_{p2} and L_{p3} are the sound pressure levels at each of the three measurement positions in the test duct.

$\overline{L_{pm}}$ is the spatially averaged sound pressure level obtained from averaging over the measurement positions in the test duct. It may also be obtained from a continuous circumferential traverse (see 7.2.4).

$\overline{L_p}$ is the spatially averaged sound pressure level at the measurement plane, corrected for the combined free-field response C (see Table 1 and 8.1).

NOTE 3 The sound pressure level is expressed in decibels (dB).

3.6
sound power level

L_W

$$L_W = 10 \lg \frac{P}{P_0} \text{ dB} \tag{2}$$

where P is the sound power and the reference sound power P_0 is equal to 1 pW

NOTE 1 The width of a restricted frequency band should be indicated, for example, octave-band sound power level, one-third-octave-band sound power level.

NOTE 2 The sound power level is expressed in decibels (dB).

3.7
fan sound power

sound power radiated into the test duct by the fan

3.8
frequency band range of interest

one-third-octave bands with centre frequencies between 50 Hz and 10 000 Hz

NOTE For information only, the frequency range of interest may be extended up to 20 000 Hz. For fans which radiate predominantly high- or low-frequency sound, the frequency range of interest may be limited in order to reduce the costs of the test facilities and procedures. The limits of the restricted frequency range shall be given in the test report.

3.9
microphone shield

device designed to protect a microphone placed in a moving airstream from self-generated wind noise and turbulent pressure fluctuations

NOTE 1 See Clause 4, Note 5.

NOTE 2 The three types are listed in order of preference in 3.9.1, 3.9.2 and 3.9.3.

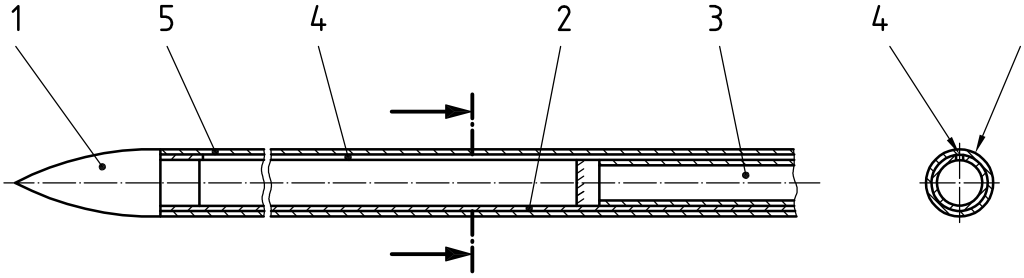
3.9.1
sampling tube
turbulence screen

metal tube with a longitudinal slit, covered by a porous material within which the microphone is positioned, designed to reduce the response of the microphone to self-induced wind noise and to turbulent pressure fluctuations of the air pressure within the duct

See Figure 1.

NOTE 1 The sampling tube is the preferred microphone shield for measurements according to this International Standard.

NOTE 2 To minimize self-induced wind noise, the outer surface of the tube should be smooth and free of any discontinuities (see Figure 1). The slit and covering of the sampling tube should be designed to reduce the response of the microphone to turbulent pressure fluctuations in the air stream emanating from the fan being tested.



Key

1 nose cone
2 slit-tube
3 microphone
4 slit
5 porous material

Figure 1 — Schematic of a sampling tube for a 13 mm (1/2 inch) microphone

3.9.2
nose cone
microphone shield designed to substitute the normal protection grid of the microphone and used in high-velocity air flows with low turbulence and little swirl having a streamlined shape with the least possible resistance to airflow and a fine wire mesh around its periphery allowing sound pressure transmission to the microphone diaphragm, whilst a truncated cone behind the mesh reduces the air volume in form of the diaphragm

See Figure 2.

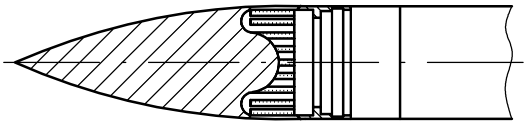


Figure 2 — Schematic of a nose cone

3.9.3
foam ball
ball of open-pored foam with a cylindrical hole of appropriate diameter for insertion of the microphone and preamplifier, designed not to affect the directivity of the microphone

See Figure 3.

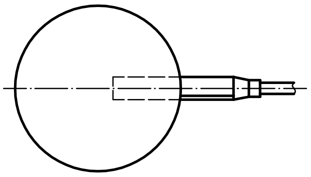


Figure 3 — Schematic of a foam ball

3.10
frequency range of plane-wave sound propagation in a duct with circular cross section

frequencies, in hertz, below the cut-on frequency of the first cross mode, $f_{1,0}$, as given by

$$f_{1,0} = 0{,}586\frac{c}{D}\sqrt{1-\left(\frac{U}{c}\right)^2} \tag{3}$$

where

c is the speed of sound, approximately 340 m/s;

D is the duct diameter, in metres;

U is the mean flow velocity, in metres per second.

Table 1 — Symbols

C_1	correction in decibels supplied by the manufacturer to be added to the calibrated microphone response to obtain the free field response.
C_2	frequency response correction in decibels of the sampling tube microphone shield at normal incidence to be added to the calibrated microphone response. (See 5.3.3 and 5.3.4.)
$C_{3,4}$	combined mean flow velocity and modal correction in decibels for the frequency response required by the use of the sampling tube microphone shield. (See tables in Annexes A, H and I.)
$C = C_1 + C_2 + C_{3,4}$	combined frequency response correction, expressed in decibels.
c	speed of sound in the test duct, in metres per second.
U	mean flow velocity in the test duct, in metres per second.
ρ	fluid density, in kilograms per cubic metre, in the duct.
d	diameter, in metres, of the fan inlet (d_1), fan outlet (d_2), test duct (d_3 and d_6 in Figure 5), intermediate ducts (d_4), terminating ducts (d_6 in Figure 6 and d_3 in Figure 7).
l	length of the ducts and transitions (see Figures 5 to 7).
r	radial distance, in metres, from the test duct centreline to the microphone centreline.
r_a	dimensionless pressure reflection coefficient defined as the ratio of the sound pressure amplitude of the sound wave reflected from the anechoic termination to the sound pressure amplitude of the incident wave.
b, h	cross dimensions, in metres, of the rectangular fan inlet or fan outlet.
S	cross-sectional areas of ducts or duct sections, in square metres.

NOTE 1 In the first edition of ISO 5136 (1990), two correction terms C_3 and C_4 were used to account for the effect of the flow and the modal distribution in the sound field on the response of the sampling tube. In the present edition, these two effects are incorporated in the new combined correction term $C_{3,4}$.

NOTE 2 $U < 0$ for inlet side measurements; $U > 0$ for outlet side measurements.

4 Uncertainty of the measurement method

Determination of sound power made in accordance with this International Standard will tend to result in an uncertainty of sound power level given in terms of the values of the standard deviation of reproducibility given in Table 2. The standard deviations given in this table reflect the cumulative effects of all causes of measurement uncertainty such as source location, duct end reflections, duct transitions, instrument calibration, sound pressure to sound power computing and sampling errors. The standard deviations given in the table are those which would be expected if the measurement of a single fan were repeated in many different laboratories. They do not include variations in the sound power radiated by the fan itself caused, for example, by changes in the mounting arrangements. Care should be taken to obtain a specified time average in accordance with the requirements laid down in 7.2.2.

Table 2 — Values of the standard deviation of reproducibility for the sampling tube

One-third-octave band centre frequency Hz	Standard deviation of reproducibility, σ_R dB
50	3,5
63	3
80 to100	2,5
125 to 4 000	2
5 000	2,5
6 300	3
8 000	3,5
10 000	4

NOTE The standard deviations given in Table 2 are derived from information in references [3], [5] and [19].

The procedures of this International Standard and the standard deviations given in Table 2 are applicable to measurements on an individual piece of equipment. Characterization of the sound power levels of batches of equipment of the same family or type involves the use of random sampling techniques in which confidence intervals are specified, and the results are expressed in terms of statistical upper limits. In applying these techniques, the total standard deviation must be known or estimated, including the standard deviation of production as defined in ISO 7574-1, which is a measure of the variation in sound power output between individual pieces of equipment within the batch. Statistical methods for the characterization of batches of equipment are described in ISO 7574-3 and ISO 7574-4.

The measurement uncertainty may be lowered by careful construction of the test set-up, by eliminating transition ducts, and by use of more absorptive terminating ducts.

For a particular family of sound sources, of similar size and with similar sound power spectra, the standard deviation of reproducibility could be smaller than the values given in Table 2. Hence, a test code for a particular type of equipment may state standard deviations smaller than those listed in Table 2 if substantiation is available from the results of suitable interlaboratory tests.

At high frequencies, particularly above 4 000 Hz, the standard deviation data quoted in Table 2 can underestimate the actual standard deviations when the noise spectrum being measured decreases rapidly with frequency. Under these conditions, the high-frequency sound pressure levels sensed by the microphone can be of small magnitude compared with those at low frequencies, and electrical noise, particularly from the frequency analyser, can interfere with the sound signal at these high frequencies. In order to achieve reproducible determinations of sound power (with standard deviations in Table 2) it may be necessary to repeat the high-frequency sound measurement by passing the microphone signal through a high pass filter before it is analysed by the frequency analyser.

NOTE 1 When octave-band sound power levels are calculated, the uncertainty of each octave-band level will not be greater than that of the largest uncertainty of the three constituent one-third-octave bands.

NOTE 2 For a normal distribution, 68 % of all data lie within an interval $\pm \sigma_R$, and 95 % lie within $\pm 2\sigma_R$.

NOTE 3 The uncertainty will increase in the presence of swirling flows.

NOTE 4 If discrete frequency components are present or if measurements are not averaged over a sufficiently long period (see 6.2.2), the uncertainty will be greater than that indicated.

NOTE 5 A microphone exposed to high air velocity will give a falsely high reading. This is rectified by fitting a shield such as a sampling tube, a nose cone or a foam ball. These are limited in their use (see 1.1) according to the mean flow velocity. Whilst the foam ball is omni-directional and reduces the wind-generated noise in all directions, a nose cone has to be aligned with the flow to reduce the wind-generated noise. Only the sampling tube, however, reduces the false noise generated by turbulent fluctuations of pressure to a sufficient degree. It is, therefore, the preferred solution for all cases. The uncertainties given in Table 2 refer to the sampling tube only and can be expected to increase for other shields.

NOTE 6 The standard deviations listed in Table 2 are associated with the test conditions and procedures defined in this International Standard and not with the noise source itself. They arise partly from variations between measurement laboratories in the geometry of the test facility, background noise, turbulent pressure fluctuations, and the type and calibration of instrumentation. They are also due to variations in experimental measurement techniques, including spatial averaging and integration times.

NOTE 7 If several laboratories use similar facilities and instrumentation, the results of sound power determinations on a given source in those laboratories may be in better agreement than would be inferred by the standard deviations of Table 2.

Measurements above 10 000 Hz may be reported, but are not considered part of this International Standard. The extrapolated values of the standard deviation given in Table 3 are suggested.

Table 3 — Extrapolated values

One-third-octave band centre frequency Hz	Standard deviation of reproducibility, σ_R dB
12 500	4,5
16 000	5
20 000	5,5

5 Test facilities and instrumentation

5.1 General requirements

The test arrangement shall consist of the fan to be tested, an intermediate duct, the test duct with anechoic termination, and the instrumentation (see Figures 5 to 7). If a fan usually used with duct work on both sides is to be tested, a termination duct with anechoic termination plus an intermediate duct shall be connected opposite to the side on which the sound power is determined.

All connections between the fan and the ducts shall be firm, unless a vibration-isolating coupling is an inherent part of the fan. The test ducts shall include provisions for mounting the microphone and sampling tube at the locations specified in 6.2.

Suitable provisions shall also be made for controlling the desired operating conditions of the fan.

It is recognised that acoustic and fan performance measurements are to be performed at the same time, and that the test arrangements of this International Standard and those of ISO 5801 should be in conformity. This requires that the common part as defined in ISO 5801 be introduced at the fan inlet and/or outlet.

NOTE 1 The presence of the “star-type” flow straightener on the fan outlet side is necessary for the measurement of the aerodynamic fan performance according to ISO 5801. However, the swirling flow entering the flow straightener may generate excess noise at the microphone position which may or may not be of higher level than the sound pressure level produced by the fan under test. On the other hand, without a flow straightener, the swirling flow around the measurement microphone may generate excess flow noise which may or may not be of higher level than the sound pressure level produced by the fan under test. For this reason, comparative sound measurements with and without the “star-type” flow straightener in position are specified (see 7.3).

NOTE 2 Examples of designs of anechoic terminations and throttling devices are given in Annex E.

5.2 Duct specifications

5.2.1 Construction of ducts and transitions

The ducts shall be straight, coaxial with the inlet or outlet of the fan, and of uniformly circular cross section. The ducts and transitions shall be manufactured either from steel having a minimum thickness of 1 mm or from a material of equivalent mass per unit area and rigidity which ensures an acoustically hard and smooth interior surface.

The ducts and transitions should preferably be treated with a vibration-damping material on the outside.

NOTE This International Standard specifies test ducts with circular cross sections. Future International Standards may involve ducts with other cross sections.

5.2.2 Duct lengths

Duct lengths shall be as specified in Figure 5.

5.2.3 Duct cross-sectional area

The duct cross-sectional areas shall be as specified in Table 4, where the inlet area S_{f1} or outlet area S_{f2} is the area on the side to which the respective duct is connected.

Table 4 — Cross-sectional areas of ducts

Duct		Cross-sectional area	
		min.	max.
Inlet side	Intermediate	1 S_{f1}	1 S_{f1}
	Test	1 S_{f1}	2,1 S_{f1}
	Terminating	1 S_{f1}	2,1 S_{f1}
Outlet side	Intermediate	0,95 S_{f2}	1,07 S_{f2}
	Test	0,7 S_{f2}	2,1 S_{f2}
	Terminating	0,7 S_{f2}	2,1 S_{f2}

5.2.4 Transition ducts

The test duct or terminating duct shall be coupled directly to the intermediate duct or, where there is a change of cross-sectional area, indirectly by means of a transition duct. The diameter ratio of the transition shall lie within the limits specified in Table 4.