INTERNATIONAL STANDARD

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Acoustics — Determination of sound power radiated into a duct by fans — In-duct method

Acoustique — Détermination de la puissance acoustique rayonnée dans un conduit par des ventilateurs — Méthode en conduit

Reference number
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Contents

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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.

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.

International Standard ISO 5136 was prepared by Technical Committee ISO/TC 43, *Acoustics.*

Annexes A and B form an integral part of this International Standard. Annexes C to G are for information only.

Introduction

The sound power radiated into a duct by a fan depends to some extent on the type of duct, characterized by its acoustical impedance. For a measurement method, the duct has, therefore, to be clearly specified. In this International Standard, the duct is of circular cross-section and terminated nearly anechoically. Details of typical anechoic terminations are given in annex C. 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 fans 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 stipulated. The microphone, with the sampling tube, is mounted at a radial position such that the sound pressure is acceptably well related to the sound power by the plane wave formula, even in the frequency range in which radial standing waves (cross-modes) are possible.

The testing precision 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 intended to be specified in a separate code which will be the subject of a future International Standard.

This International Standard is one of a series specifying different methods for determining the sound power levels of fans.

Acoustics — Determination of sound power radiated into a duct by fans — In-duct method

1 Scope

1.1 Measurement conditions

This International Standard specifies a method for testing ducted fans to determine the sound power radiated into an anechoically-terminated duct on the inlet and/or outlet side of the equipment. It applies to fans which emit steady, broad-band, narrow-band and discrete-frequency sound. It applies to air temperatures between − 50 °C and + 70 °C.

The test duct diameter range is from 0,15 m to 2 m. The maximum flow velocity is 30 m/s and the maximum swirl angle is 15°. An example of a method for determining the angle of swirl is given in annex F.

The one-third octave band centre frequency range is from 50 Hz to 10 000 Hz.

NOTE — The flow noise suppression of the sampling tube (see 6.2.1) may be insufficient at higher velocities and at higher angles of swirl.

1.2 Types of source

The method applies to a sound source in which a fan is usually connected to ducts on at least one side.

Examples of the ducted fans and fan equipment covered by this International Standard are

- ducted centrifugal fans;
- ducted axial flow fans;
- ducted mixed flow fans.

This International Standard may also apply to other aerodynamic sources, such as boxes, dampers and throttle devices.

This International Standard does not apply to non-ducted fans or non-ducted fan equipment.

1.3 Precision of the method of measurement

The precision of the method of measurement is given in terms of the standard deviation of the sound power level. It includes the effects of end reflections, transitions, the possible errors in computing sound power from pressure measurements, and the tolerance of the instrument calibration. The estimated standard deviations are given in table 1.

Table 1 — Precision of the method of measurement

One-third octave band centre frequency Hz	Standard deviation dB
50	3,5
63	3
80; 100	2,5
125 to 4 000	2
5 000	2,5
6 300	3
8 000	3,5
10 000	4

The standard deviations given in table 1 reflect the cumulative effects of all causes of measurement uncertainty, excluding variations in the sound power from machine to machine or from test to test which may be caused, for example, by changes in the mounting or operating conditions of the source.

NOTES

1 The standard deviations given in table 1 are derived from information in [3], [5] and [19].

2 The precision data will increase in the presence of swirling flows.

3 If discrete frequency components are present or if measurements are not averaged over a sufficiently long period, the precision will be less than that indicated.

4 At high frequencies, particularly above about 4 000 Hz, the precision data quoted in table 1 may increase 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 lower frequencies, and electrical noise, particularly from the frequency analyser, can interfere with the sound signal at these high frequencies. In order to achieve correct determinations of sound power 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.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 266 : 1975, *Acoustics — Preferred frequencies for measurements.*

ISO 5221 : 1984, *Air distribution and air diffusion — Rules to methods of measuring air flow rate in an air handling duct.*

ISO 7235 : —[1], *Acoustics — Measurement procedures for ducted silencers — Insertion loss, flow noise and total pressure loss.*

IEC 225 : 1966, *Octave, half-octave and third-octave band filters intended for the analysis of sounds and vibrations.*

IEC 651 : 1979, *Sound level meters.*

3 Definitions and symbols

For the purposes of this International Standard, the following definitions and symbols apply.

3.1 fan inlet [outlet] area, S_f**:** The area of the fan fitting provided for connection to attached ductwork.

3.2 ducts: Any of the airways defined in 3.2.1, 3.2.2 and 3.2.3.

3.2.1 test duct: The duct in which the fan sound power is measured. It has an anechoic termination.

3.2.2 terminating duct: The duct opposite to the test duct, if both sides of the fan are ducted. It has an anechoic termination.

3.2.3 intermediate duct: The duct fitted on the intake side and on the discharge side of the fan to ensure desired flow conditions. It connects to the test duct or the terminating duct, if necessary by a transition section (see figure 1).

3.3 measurement plane: The radial plane in the test duct in which the microphone diaphragm is located.

3.4 sound pressure level, L_p**, in decibels:** Ten times the logarithm to the base 10 of the ratio of the mean-square sound pressure of a sound to the square of the reference sound pressure. The width of a restricted frequency band shall be indicated, for example one-third octave band pressure level, A-weighted sound pressure level, etc. The reference sound pressure is 20 µPa.

L_{p1}, L_{p2}, 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 6.2.4).

$\overline{L_p}$ is the spatially averaged sound pressure level at the measurement plane, corrected for the combined free-field response C (see 3.9 and 7.1).

3.5 sound power level, L_W**, in decibels:** Ten times the logarithm to the base 10 of the ratio of a given sound power to the reference sound power. The width of a restricted frequency band shall be indicated, for example one-third octave band power level, A-weighted sound power level, etc. The reference sound power is 1 pW.

3.6 fan sound power: The sound power radiated into the test duct by the fan.

3.7 frequency range of interest: For general purposes, the frequency range of interest includes the one-third octave bands with centre frequencies between 100 Hz and 10 000 Hz. For special purposes, the frequency range of interest may be extended down to 50 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.

3.8 sampling tube: A tubular windscreen to be attached to a standard microphone designed to minimize its sensitivity to flow noise.

3.9 Further symbols

C_1 correction supplied by the manufacturer to be added to the calibrated microphone response to obtain the free field response, expressed in decibels

C_2 frequency response correction of the sampling tube of normal incidence, expressed in decibels, to be added to the calibrated microphone response [see 4.3.3 c)]

C_3 flow velocity correction for the frequency response required by the use of the sampling tube, expressed in decibels (see table 5)

C_4 modal correction for the frequency response required by the use of the sampling tube, expressed in decibels (see table 6)

$C = C_1 + C_2 + C_3 + C_4$ combined frequency response correction, expressed in decibels

c speed of sound in the test duct

ϱ fluid density in the test duct

1) To be published.

d diameter of the fan inlet, fan outlet, test duct, intermediate ducts, terminating ducts (see figure 1)

l length of the ducts and transitions (see figure 1)

r radial distance from the test duct centreline to the sampling tube centreline

r_a 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 of the rectangular fan inlet or fan outlet

4 Test facilities and instrumentation

4.1 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 figure 1). 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 5.2.

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

NOTES

1 Examples of designs of anechoic terminations and throttling devices are given in annex C.

2 Measurement of mass flow is the preferred method of controlling the fan operating point (see ISO 5221); an alternative method is to measure the fan pressure rise.

3 The aerodynamic performance characteristics of the fan may be measured using a different test arrangement.

4.2 Duct specifications

4.2.1 Construction of ducts and transitions

The ducts shall be straight, coaxial with the fan inlet or outlet, and of uniformly circular cross-section. The ducts and transitions shall be manufactured either from steel having a minimum thickness 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 prescribes ducts with circular cross-sections. Future International Standards may involve ducts with rectangular cross-sections.

4.2.2 Duct lengths

Duct lengths shall be as specified in figure 1.

4.2.3 Duct cross-sectional area

The duct cross-sectional areas shall be as specified in table 2, where the inlet or outlet area S_f is the area on the side to which the respective duct is connected.

Table 2 — Cross-sectional areas of ducts

Duct		Cross-sectional area min.	Cross-sectional area max.
Fan inlet side	Intermediate	1 S_f	1 S_f
	Test	1 S_f	2,1 S_f
	Terminating	1 S_f	2,1 S_f
Fan outlet side	Intermediate	0,95 S_f	1,07 S_f
	Test	0,7 S_f	2,1 S_f
	Terminating	0,7 S_f	2,1 S_f

4.2.4 Transitions

All transitions, including any transitions from rectangular fan outlets or inlets to the circular ducts, shall be coaxial and shall meet the following criteria:

a) the maximum enclosed angle of the sides shall be 15°;

b) the minimum length, l_{min}, shall be calculated from

$$\frac{l_{min}}{l_0} = \frac{\text{larger area}}{\text{smaller area}} - 1$$

with $l_0 = 1$ m

4.2.5 Anechoic termination

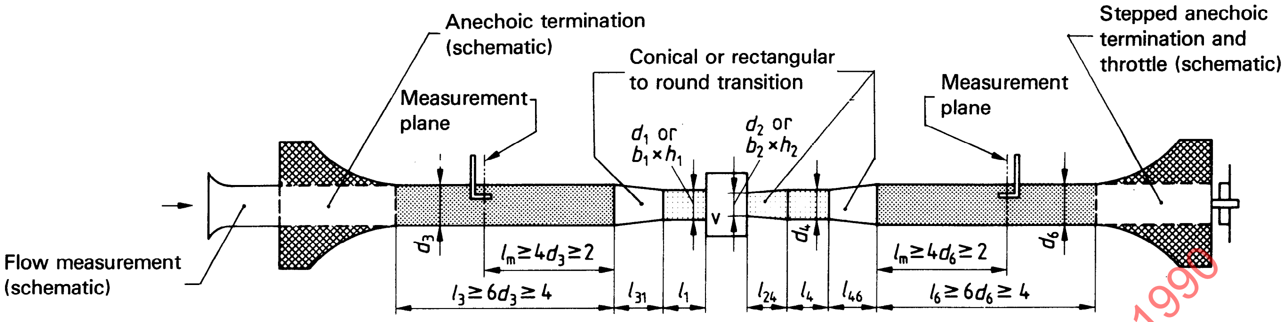
The pressure reflection coefficient, r_a, of the anechoic termination when installed and when a throttling device is fitted shall not exceed the values specified in table 3.

Table 3 — Maximum pressure reflection coefficients

One-third octave band centre frequency Hz	Maximum pressure reflection coefficient
50	0,4
63	0,35
80	0,3
100	0,25
⩾ 125	0,15

NOTE — Guidelines for the design of the anechoic terminations and a method for measuring the pressure reflection coefficient of the termination are given in annexes C and D.

Dimensions in metres



For circular fan inlet, diameter d_1

$1 < (d_3/d_1)^2 < 2{,}1$

$2d_1 < l_1 < 5d_1$

$l_{31} > 3{,}8\,(d_3 - d_1)$ and $> (d_3/d_1)^2 - 1$

For rectangular fan inlet, $b_1 \times h_1$

$$1 < \frac{\pi d_3^2}{4b_1h_1} < 2{,}1$$

$$2\sqrt{\frac{4b_1h_1}{\pi}} < l_1 < 5\sqrt{\frac{4b_1h_1}{\pi}}$$

$$b_{31} > 3{,}8\left|\sqrt{b_1^2 + h_1^2} - d_3\right| \text{ and } > \frac{\pi d_3^2}{4b_1h_1} - 1$$

$2d_4 < l_4 < 5d_4$

$l_{46} > 3{,}8\,(d_6 - d_4)$ and $> (d_6/d_4)^2 - 1$
for $d_6 > d_4$

$l_{46} > 3{,}8\,(d_4 - d_6)$ and $> (d_4/d_6)^2 - 1$
for $d_4 > d_6$

For circular fan outlet, diameter d_2

$0{,}95 < (d_4/d_2)^2 < 1{,}07$

$0{,}7 < (d_6/d_2)^2 < 2{,}1$

$l_{24} > 3{,}8\,(d_4 - d_2)$ and $> (d_4/d_2)^2 - 1$
for $d_4 > d_2$

$l_{24} > 3{,}8\,(d_2 - d_4)$ and $> (d_2/d_4)^2 - 1$
for $d_2 > d_4$

For rectangular fan outlet, $b_2 \times h_2$

$$0{,}95 < \frac{\pi d_4^2}{4b_2h_2} < 1{,}07$$

$$0{,}7 < \frac{\pi d_6^2}{4b_2h_2} < 2{,}1$$

$$l_{24} > 3{,}8\left|\sqrt{b_2^2 + h_2^2} - d_4\right| \text{ and } > \frac{\pi d_4^2}{4b_2h_2} - 1$$

for $\frac{\pi}{4} d_4^2 > b_2h_2$

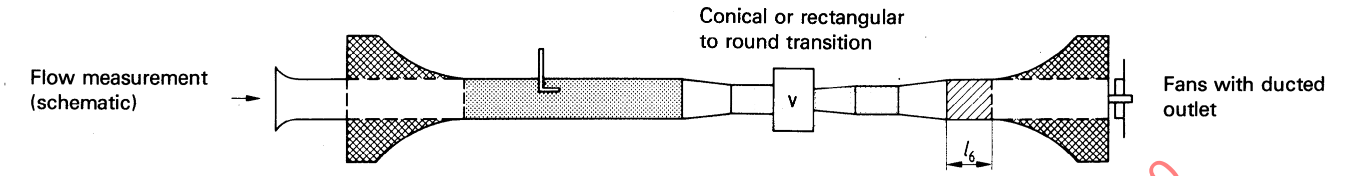
$$l_{24} > 3{,}8\left|\sqrt{b_2^2 + h_2^2} - d_4\right| \text{ and } > \frac{4b_2h_2}{\pi d_4^2} - 1$$

for $b_2h_2 > \frac{\pi}{4} d_4^2$

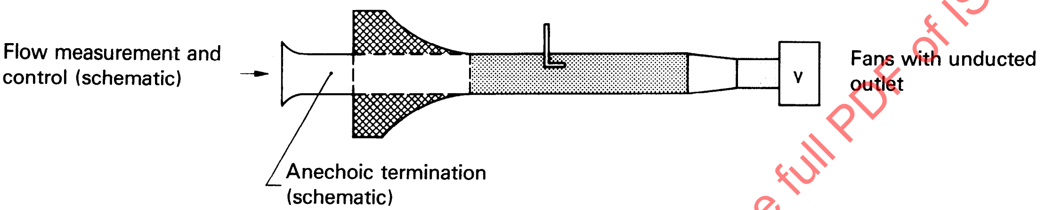
a) Simultaneous measurement of inlet and outlet in-duct noise

Figure 1 — Test arrangement and limiting dimensions of test ducts, intermediate ducts and transitions

Dimensions in metres



All dimensions as for figure 1 a) except for l_6
$l_6 \geqslant d_6$ and $\geqslant 1$

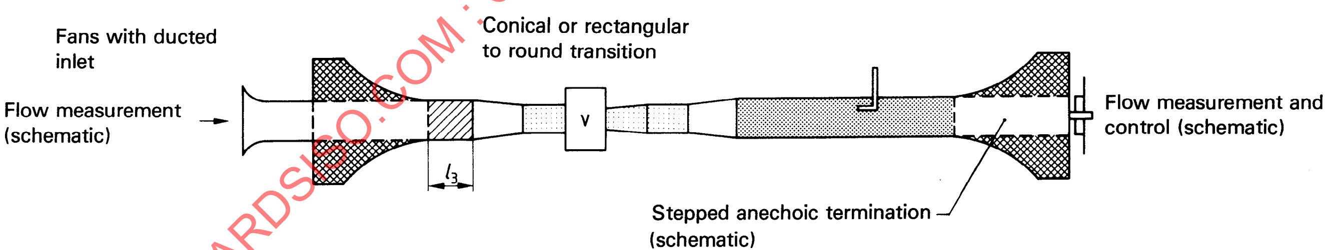


All dimensions as for figure 1 a)

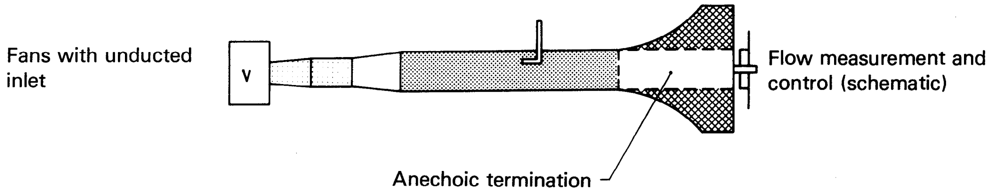
b) Measurement of inlet in-duct noise only

Figure 1 — (*continued*)

Dimensions in metres

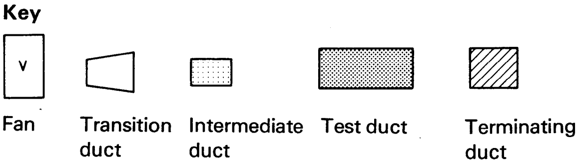


All dimensions as for figure 1 a) except for l_3
$l_3 \geqslant 4d_3$ and $\geqslant 1$



All dimensions as for figure 1 a)

Key



c) Measurement of outlet in-duct noise only

Figure 1 — (*concluded*)

4.2.6 Throttling device

An adjustable throttling device, if necessary, shall be provided at the end of the anechoic termination remote from the fan. No other throttle shall be placed between the fan and the anechoic termination. The throttling section shall provide control to adjust the operating conditions under which it is desired to determine the sound power of the fan.

The throttling device and the anechoic termination shall be designed so that the sound pressure level generated in the test duct by the throttling device is at least 10 dB below the fan sound pressure level in the test duct.

Suggested throttling arrangements are shown in figure C.5.

4.3 Instrumentation

4.3.1 Measuring system

4.3.1.1 Microphone

A microphone of a sound level meter complying with the requirements for a type 1 instrument as specified in IEC 651 shall be used. The dimensions shall be compatible with those of the sampling tube.

4.3.1.2 Microphone cable

The microphone/cable system shall be such that the sensitivity does not change with temperature in the range prevailing during the test. Cable flexing arising from either microphone traversing or from airflow across the cable shall not introduce noise which interferes with the measurements.

4.3.1.3 Sound level meter or other microphone amplifier

The sound level meter or other amplifier used to amplify the microphone signal shall conform to the electrical requirement for a type 1 sound level meter as specified in IEC 651. The frequency response characteristic designated Lin shall be used.

4.3.2 Frequency analyser

A one-third octave band filter set complying with the requirements of IEC 225 shall be used. The filter band centre frequencies shall be those tabulated in ISO 266.

4.3.3 Sampling tube

The sampling tube reduces the turbulent pressure fluctuations at the measurement positions in order to maintain a sufficient signal-to-noise ratio (see 6.2.1).

The sampling tube and its use shall comply with the following requirements:

a) The turbulence noise shall be suppressed by at least 10 dB in the frequency range of interest as compared with a nose cone. The actual values of turbulence noise suppression as a function of frequency and flow velocity shall be known in order to determine the signal-to-noise ratio as specified in 6.2.1 (see also annex B and table E.1).

b) The maximum diameter of the sampling tube shall be 22 mm.

c) The frequency response correction C_2 of the sampling tube for each one-third octave band of interest shall be determined to within ± 0,5 dB in a plane-wave field incident axially from the front. If tests are carried out in a free field, a minimum distance of 3 m between the loudspeaker and the sampling tube being tested shall be maintained, and the reference microphone position shall be at the mid-point of the sampling tube length. It is essential that the frequency response correction curve be smooth. Alternatively, a manufacturer's calibration curve, obtained in compliance with the requirements for the frequency response correction, shall be used.

d) The directivity of the sampling tube, when measured in a free field with broad-band noise of one-third octave bandwidth, shall be within the limits given in figure 2.

NOTES

1 Curves illustrated in figure 2 are given by the following equation:

$$\Delta L = 20 \lg \frac{1}{1 + f_o \times K \times \Theta^3} \quad \text{for } 0 < \Theta < 1,31 \text{ rad } (75°)$$

where

ΔL is the reduction of sensitivity, in decibels, at an incidence angle Θ compared with incidence axially from front (Θ = 0°);

K is the directivity constant;

f_o is the centre frequency of the one-third octave band, in hertz;

Θ is the angle of incidence, in radians.

The limiting values of the directivity constant K are given in table 4.

Table 4 — Limiting values of the directivity constant K

One-third octave band centre frequency Hz	K_{min}	K_{max}
1 000	$0,35 \times 10^{-3}$	$1,5 \times 10^{-3}$
2 000	$0,35 \times 10^{-3}$	$1,5 \times 10^{-3}$
4 000	$0,35 \times 10^{-3}$	$2,2 \times 10^{-3}$
8 000	$0,35 \times 10^{-3}$	$2,2 \times 10^{-3}$

2 A manufacturer's statement that the sampling tube directivity is within the limits specified by figure 2 may be used.

e) Values for the flow velocity correction, C_3, shall be taken from table 5.

NOTE — Sampling tubes are available commercially. See for example figure E.1.

f) Values for the modal correction, C_4, shall be taken from table 6.

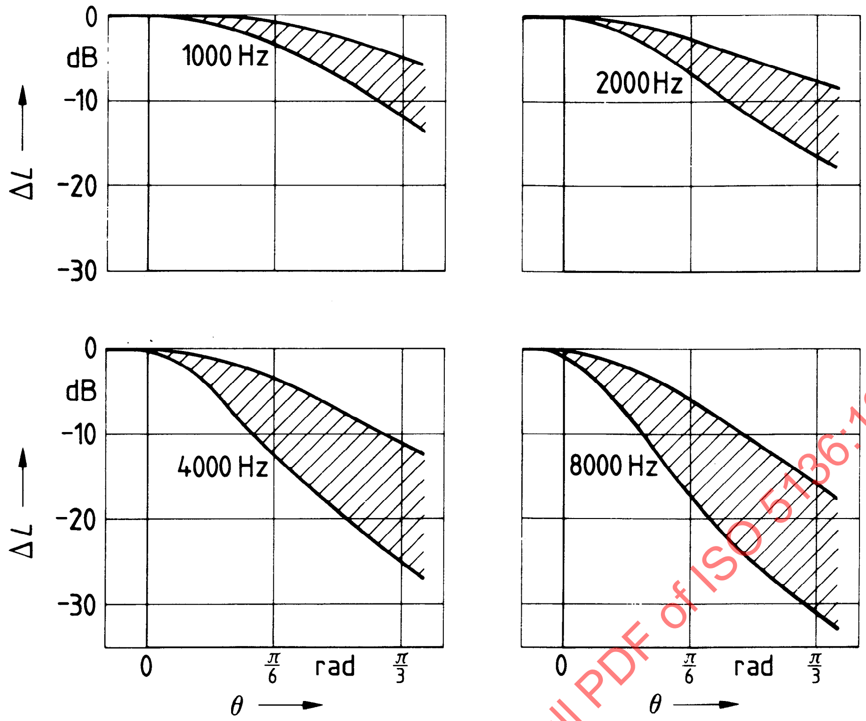


Figure 2 — Limiting curves for the directivity of the sampling tube (broad-band noise of one-third octave bandwidth)

Table 5 — Flow velocity correction, C_3, in decibels, for the frequency response of the sampling tube

One-third octave band centre frequency	Range of flow Mach numbers (flow velocity/speed of sound)												
	0,011 7 to < 0,017 5	0,017 5 to < 0,023 3	0,023 3 to < 0,029 2	0,029 2 to < 0,035 0	0,035 0 to < 0,040 8	0,040 8 to < 0,046 6	0,046 6 to < 0,052 5	0,052 5 to < 0,058 3	0,058 3 to < 0,064 1	0,064 1 to < 0,070 0	0,070 0 to < 0,075 8	0,075 8 to < 0,081 6	0,081 6 to < 0,087 5
	Range of flow velocities, in metres per second, for measurements in air at 20 °C (i.e. speed of sound, c = 343 m/s)												
Hz	4 to < 6	6 to < 8	8 to < 10	10 to < 12	12 to < 14	14 to < 16	16 to < 18	18 to < 20	20 to < 22	22 to < 24	24 to < 26	26 to < 28	28 to < 30
1 000	— —	— —	— —	— —	— —	— —	— —	— —	— —	— —	0,2 —	0,2 —	0,2 —
1 250	— —	— —	— —	— —	— —	— —	— —	— —	0,2 —	0,2 —	0,2 —	0,2 —	0,3 —
1 600	— —	— —	— —	— —	— —	— —	0,2 —	0,2 —	0,2 —	0,3 0,2	0,3 0,2	0,3 0,3	0,4 0,3
2 000	— —	— —	— —	— —	— —	0,2 —	0,2 —	0,3 0,2	0,3 0,2	0,4 0,3	0,4 0,4	0,5 0,4	0,5 0,5
2 500	— —	— —	— —	— —	0,2 —	0,2 0,2	0,3 0,3	0,4 0,3	0,4 0,4	0,5 0,5	0,6 0,6	0,7 0,7	0,8 0,9
3 150	— —	— —	— —	0,2 0,2	0,3 0,2	0,4 0,3	0,5 0,4	0,6 0,6	0,7 0,7	0,8 0,9	0,9 1	1 1,2	1,2 1,5
4 000	— —	— —	0,2 0,2	0,3 0,3	0,4 0,4	0,6 0,6	0,7 0,7	0,9 0,9	1 1,2	1,2 1,5	1,4 1,8	1,6 2,1	1,9 2,5
5 000	— —	0,2 0,2	0,3 0,3	0,5 0,5	0,6 0,7	0,8 0,9	1,1 1,2	1,3 1,5	1,6 1,9	1,9 2,3	2,2 2,8	2,6 3,4	2,9 4
6 300	0,2 —	0,3 0,3	0,5 0,5	0,7 0,8	1 1,1	1,3 1,5	1,7 2	2,1 2,5	2,5 3,1	3 3,8	3,5 4,6	4,1 5,5	4,6 6,5
8 000	0,3 0,2	0,5 0,5	0,8 0,8	1,2 1,3	1,6 1,8	2,1 2,5	2,7 3,2	3,4 4,1	4,1 5,2	4,9 6,4	5,7 7,7	6,6 9	7,5 10,4
10 000	0,4 0,4	0,8 0,8	1,2 1,3	1,8 2	2,5 2,9	3,3 3,9	4,3 5,2	5,3 6,6	6,4 8,2	7,7 9,9	8,9 11,4	10,1 12,4	11,1 12,6

NOTE — For each frequency, the upper values are for the outlet duct (sound and flow in the same direction) and the lower values are for the inlet duct (sound and flow in opposite directions).

Table 6 — Modal correction, C_4, for the frequency response of the sampling tube

One-third octave band centre frequency Hz	Diameter range of the test duct, d, in metres — Relative radial position $2r/d = 0{,}8$			Relative radial position $2r/d = 0{,}65$		
	$0{,}15 \leqslant d < 0{,}2$	$0{,}2 \leqslant d < 0{,}3$	$0{,}3\ d \leqslant d < 0{,}5$	$0{,}5 \leqslant d < 0{,}8$	$0{,}8 \leqslant d < 1{,}25$	$1{,}25 \leqslant d \leqslant 2$
250						
315						1
400						1,5
500					1	1,5
630				1	1,5	1,5
800				1,5	1,5	1,5
1 000				2	2	2
1 250			1	2	2	2
1 600	1	1	1,5	2,5	2,5	2,5
2 000	1	2	2,5	3	3	3
2 500	1,5	2,5	3	3,5	3,5	3,5
3 150	2,5	3,5	4	4	4	4
4 000	3,5	4,5	5	5	5	5
5 000	4,5	5,5	5,5	5,5	5,5	5,5
6 300	5,5	6	6	6	6	6
8 000	6	6	6	6	6	6
10 000	6	6	6	6	6	6

g) An example of a sampling tube is given in annex E. A typical reduction of the turbulent pressure fluctuation as compared with the nose cone is given in table E.1 as a function of flow velocity for one-third octave bands.

NOTE — Sampling tubes are available commercially. See for example figure E.1.

4.3.4 Graphic level recorder or other read-out devices

Graphic level recorders and other read-out devices shall comply with the requirements for a type 1 instrument as specified in IEC 651.

4.3.5 Multiplexing system

If the procedure outlined in 5.2.2b) is used, the multiplexing system shall be qualified such that the resulting sound pressure level is within ± 0,5 dB of the true energy-equivalent average of the individual sound pressure levels throughout the frequency range of interest.

4.4 System calibration

A stable acoustical calibrator shall be applied to the microphone without the sampling tube to check the calibration of the entire measuring system before and after each series of tests. The calibrator shall be recalibrated annually. The porous part of the sampling tube shall be clean and undamaged.

5 Test arrangement

5.1 Sampling tube mounting

The microphone with the sampling tube shall be mounted in the test duct in the measuring plane as shown in figure 1.

The microphone with the sampling tube shall be mounted rigidly in an axial direction pointing towards the fan. For fan inlet measurements, the sampling tube shall point towards the fan, but the microphone end of the tube shall be rounded. The mounting shall introduce a minimum of flow noise.

NOTE — Schematic drawings of typical mountings are given in annex E.

5.2 Sampling tube position

5.2.1 Radial position

The sampling tube shall be mounted at the radial positions given in table 7. See figure 3.

Table 7 — Radial positions of the sampling tube

Diameter of the test duct, d m	Relative radial position $2r/d$
$0{,}15 \leqslant d < 0{,}5$	0,8
$0{,}5 \leqslant d \leqslant 2$	0,65
NOTE — The given radial positions ensure a good estimate of the sound power from the measured sound pressure.	

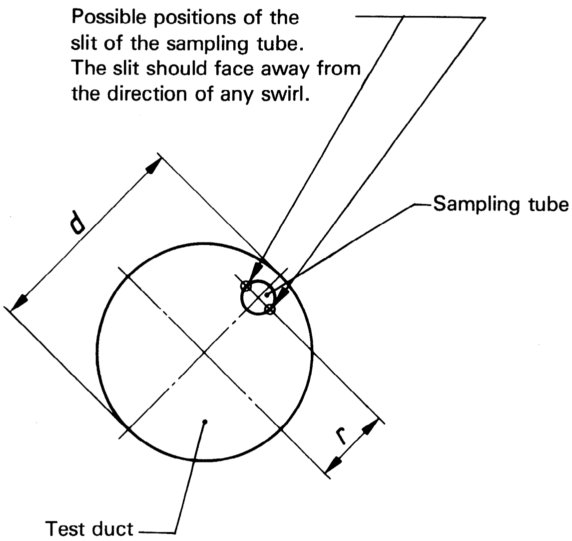


Figure 3 — Radial position of the sampling tube

5.2.2 Circumferential positions

At the radial positions specified in 5.2.1, a circumferential mean value of the sound pressure level shall be obtained by using one of the following procedures:

a) A single microphone moved sequentially to at least three microphone positions distributed equally on the circumference.

This may be achieved by fixing the microphone in a short duct section which can be rotated in equal intervals.

b) Three of more fixed microphones equally distributed on the circumference. If the signals of these microphones are to be averaged using a multiplexing system, they shall have the same type of sampling tube fitted and their sensitivities shall be equalized to ensure that they have equal frequency response corrections to within 0,5 dB.

c) One microphone with a continuous circumferential traverse at constant angular velocity through one complete revolution.

If the porous part of the sampling tube consists of one slit only, this slit shall be located in the circumferential direction opposite to the incidence of the swirl component.

5.3 Operating condition control equipment

The equipment specified in 4.1 and 4.2.6 used to control the operating conditions shall not interfere with the acoustical measurements (see 6.2.1).

6 Test procedure

6.1 Operating conditions

The operating conditions shall be determined by the procedures which will be specified in a future International Standard.

6.2 Sound pressure level readings

6.2.1 General

Measurements shall be made in one-third octave bands within the frequency range of interest.

Sound pressure level readings shall be taken under the required steady-state fan operating conditions. The background noise levels with the fan being tested not operating should be measured for each test condition. The fan sound pressure level readings shall be at least 10 dB above the background levels. If the background noise is less than 10 dB below the sound pressure level, the data shall be reported as "Not more than ... dB above background noise".

The fan sound pressure level readings shall be at least 6 dB above the level of the turbulent pressure fluctuations which are associated with the turbulent flow in the test duct. One of the two procedures for determining this signal-to-noise ratio described in annex B shall be used. Where the fan sound pressure level is less than 6 dB above the level of the turbulent pressure fluctuations, the data shall be reported as "No more than ... dB above the level of turbulent pressure fluctuations", and no correction for turbulent pressure fluctuations shall be made.

6.2.2 Sampling time

At each one of the three measurement positions described in 5.2.2 [see procedure outlined in a) or b)], an energy-equivalent time-averaged sound pressure level shall be obtained. For frequency bands centred on or below 160 Hz, the period of observation shall be at least 30 s. For the frequency bands centred on or above 200 Hz, the period of observation shall be at least 10 s. Longer observation periods may be required if the measured sound varies with time. The average sound pressure level shall be recorded to the nearest 0,5 dB for each one-third octave band within the frequency range of interest.

6.2.3 Microphone multiplexing

With microphone multiplexing [see procedure outlined in 5.2.2 b)], it is necessary only to record the temporally and spatially averaged sound pressure level (energy-equivalent level) $\overline{L_{pm}}$ for each one-third octave band within the frequency range of interest. The minimum averaging time shall be 30 s per band.

6.2.4 Continuous circumferential average

A circumferential traverse [see procedure outlined in 5.2.2 c)], if used, shall be such that the microphone is moved through one revolution in 30 s or more, at constant angular velocity, for each one-third octave band.

7 Calculations

7.1 Average sound pressure level

Where measurements of sound pressure level are made at discrete positions (see 6.2.2), the average sound pressure level, $\overline{L_p}$, in decibels, for each frequency band shall be calculated using the formula

$$\overline{L_p} = 10 \lg \left[\frac{1}{n} \sum_{i=1}^{n} 10^{0,1 L_{pi}} \right] + C$$

where

n is the number of measurement positions (not less than 3; see 5.2.2);

L_{pi} is the time-averaged sound pressure level, in decibels, at the ith measurement position;

C is the combined frequency response correction of the microphone-sampling tube combination and is given by the formula

$$C = C_1 + C_2 + C_3 + C_4$$

where

C_1 is the microphone response correction (see 3.9),

C_2 is the frequency response correction of the sampling tube,

C_3 is the flow velocity correction of the sampling tube,

C_4 is the modal correction,

where

C_1 shall be taken from the microphone manufacturer's data,

C_2, C_3 and C_4 shall be determined in accordance with the requirements of 4.3.3.

If the highest and lowest values of L_{pi} do not differ by more than 4 dB, $\overline{L_p}$ is obtained using the formula

$$\overline{L_p} = \frac{1}{n} \left[\sum_{i=1}^{n} L_{pi} \right] + C$$

If microphone multiplexing (see 6.2.3) or a continuous circumferential traverse (see 6.2.4) is used to obtain $\overline{L_{pm}}$, the average sound pressure level for each frequency band is calculated from the formula

$$\overline{L_p} = \overline{L_{pm}} + C$$

7.2 Sound power level

The sound power level, L_W, in decibels, of the sound radiated into the test duct for each frequency band is obtained by using the plane wave formula

$$L_W = \overline{L_p} + 10 \lg \frac{S}{S_o} - 10 \lg \frac{\varrho c}{(\varrho c)_o}$$

where

$S\ (= \pi d^2/4)$ is the cross-sectional area of the test duct;

$S_o = 1\ \text{m}^2$;

$(\varrho c)_o = 400\ \text{Ns/m}^3$.

The A-weighted sound power level of the sound radiated into the test duct shall be determined in accordance with annex A.

8 Information to be recorded

The following information, when applicable, shall be compiled and recorded for all measurements made in accordance with the requirements of this International Standard:

a) a description of the fan and its accessories;

b) the operating conditions;

c) the instrumentation used (types, serial numbers, manufacturers, method of calibration);

d) a description of the ducts used, including lengths and cross-sectional areas (or diameters), and description of the anechoic termination(s);

e) acoustical data

— circumferential positions of sampling tube in accordance with options a), b) or c) given in 5.2.2,

— corrections C_1, C_2, C_3, C_4 and sound power levels in one-third octave bands within the frequency range of interest,

— A-weighted sound power level, if required.

9 Information to be reported

The test report shall contain the statement that the sound power levels have been obtained in compliance with the requirements of this International Standard. The report shall state that the sound power levels are given in decibels (reference: 1 pW).

Annex A
(normative)

Computational procedures for calculating A-weighted sound power level from octave or one-third octave band power levels

Calculate the A-weighted sound power level, L_{WA}, in decibels (reference 1 pW), from the formula

$$L_{WA} = 10 \lg \sum_{j_{min}}^{j_{max}} 10^{0,1\,[(L_W)_j + C_j]}$$

where

$(L_W)_j$ is the level in the jth third-octave band;

$j_{max} = 27$;

C_j is given in table A.1.

Table A.1 — Values of C_j

j	One-third octave band centre frequency Hz	C_j
1	50	−30,2
2	63	−26,2
3	80	−22,5
4	100	−19,1
5	125	−16,1
6	160	−13,4
7	200	−10,9
8	250	−8,6
9	315	−6,6
10	400	−4,8
11	500	−3,2
12	630	−1,9
13	800	−0,8
14	1 000	0
15	1 250	0,6
16	1 600	1
17	2 000	1,2
18	2 500	1,3
19	3 150	1,2
20	4 000	1
21	5 000	0,5
22	6 300	−0,1
23	8 000	−1,1
24	10 000	−2,5
25	12 500	−4,3
26	16 000	−6,6
27	20 000	−9,3

Annex B
(normative)

Determination of the signal-to-noise ratio of sound to turbulence noise in the test duct

Two procedures for determining the signal-to-noise ratio of sound to turbulence are given in clauses B.1 and B.2. The method described in B.1 is applicable only if the angle of swirl of the flow is not more than 15°.

B.1 Comparative procedure using a microphone fitted with a nose cone and a microphone fitted with a sampling tube

This procedure requires two measurements:

a) one using a microphone fitted with a nose cone, and

b) one using a microphone fitted with a sampling tube.

The method is based on the assumption that the sound signal emitted by a noise source and the turbulence noise excited by the flow at the microphone are mutually uncorrelated and on the experimental observation that there is a difference ΔL_t between the turbulence noise levels sensed by a nose cone microphone and by a microphone fitted with a sampling tube; this difference ΔL_t has to be known as a function of mean flow velocity and frequency (see, for example, table E.1).

The condition, stated in 6.2.1, specifying that the sound pressure level reading shall be at least 6 dB above the turbulence noise level (using the sampling tube), is equivalent to another condition: that the difference between the readings of a nose cone microphone and a sampling tube microphone does not exceed a limit ΔL_{max} which is a function of the turbulence noise suppression ΔL_t of the sampling tube (see table B.1).

With the fan under test installed and operating, the following steps are necessary to check whether the signal-to-noise ratio of sound to turbulence noise in the test duct is at least 6 dB:

a) Step 1: Measure the flow velocity in the duct at the specified radial position of the sampling tube microphone (see table 7) and determine the turbulence noise suppression value ΔL_t (for example, from the manufacturer's data or, for the sampling tube design shown in figure E.1, from table E.1).

b) Step 2: Measure the circumferentially averaged sound pressure level in the duct (by using one of the procedures described in 6.2.2 to 6.2.4) with a microphone fitted with a sampling tube placed at its specified radial position (see table 7), apply the combined frequency response correction C (= $C_1 + C_2 + C_3 + C_4$) and record the result as $\overline{L_{pST}}$.

c) Step 3: Measure the circumferentially averaged sound pressure level in the duct (by using one of the procedures described in 6.2.2 to 6.2.4) with a microphone fitted with nose cone placed midway between the duct axis and the wall ($2\,r/d = 0{,}5$), apply the microphone response C_1 (see 3.9) and record the result as $\overline{L_{pNC}}$.

d) Step 4: Check whether the difference between the circumferentially averaged sound pressure levels obtained with the nose cone and the sampling tube ($\overline{L_{pNC}} - \overline{L_{pST}}$) is smaller than or equal to the maximum allowable difference ΔL_{max} given in table B.1. If the difference ($\overline{L_{pNC}} - \overline{L_{pST}}$) is larger than ΔL_{max}, then the turbulence noise is less than 6 dB below the sound pressure level reading when using the sampling tube.

Table B.1 — Maximum allowable difference between the sound pressure level readings of a microphone fitted with a nose cone, $\overline{L_{pNC}}$, and of a microphone fitted with a sampling tube, $\overline{L_{pST}}$, as a function of the turbulence noise suppression ΔL_t of the sampling tube, for a minimum signal-to-noise ratio of sound to turbulence noise of 6 dB

ΔL_t dB	$\Delta L_{max} = (\overline{L_{pNC}} - \overline{L_{pST}})_{max}$ dB
10	5,1
11	5,9
12	6,7
13	7,6
14	8,5
15	9,4
16	10,3
17	11,3
18	12,2
19	13,2
20	14,1
21	15,1
22	16,1
23	17,1
24	18,1
25	19

B.2 Procedure using a silencer

This procedure requires, for the relevant fan operating condition, two determinations of the average sound pressure level $\overline{L_p}$, calculated in accordance with 7.1, for each frequency band using a microphone with a sampling tube. For the first determination, the test duct as specified in this International Standard shall be used. For the second determination, that part of the test duct which lies between the fan and the measurement plane is replaced by a silencer which has the same cross-sectional area and the same length as the replaced part of the test duct. The silencer shall have an insertion loss of at least 10 dB for each frequency band of interest (see ISO 7235).

The requirement for the minimum signal-to-noise ratio of the sound to turbulence noise of 6 dB (see 6.2.1) is fulfilled if the average sound pressure level determined using the silencer is at least 5 dB below the level determined without using the silencer. This condition shall be met for each frequency band of interest.

Annex C
(informative)

Guidelines for the design and construction of an anechoic termination

C.1 The primary feature of an anechoic termination is a sufficiently gradual change in duct area to suppress the reflection of the sound waves back into the duct where they would interfere with the sound level measurements. The criterion for this is specified in 4.2.5 in terms of a maximum permissible pressure reflection coefficient. A procedure for determining whether a given termination meets the requirements of 4.2.5 is described in annex D.

C.2 A number of different designs meeting the requirements of 4.2.5 have been described in, for example, [2], [4], [6], [9], [12], [13], [14], [17] and [18].

C.3 Designs which have been successfully used in several laboratories are shown in detail in figures C.1 to C.4. In these designs the gradual change in the cross-sectional area of the duct approximates an exponential or a catenoidal horn. The latter gives a slightly better performance than an exponential horn. As in most successful anechoic terminations, part of the horn is filled with absorptive material to provide attenuation for the noise of devices used for controlling and measuring the air flow which are usually attached to the end of the horn. Details of the performance of these horns and the effect of various design alternatives are given in [6], [9] and [12].

It is not necessary to adhere exactly to the exponential or catenoidal profile. Approximation to these profiles by conical sections, as shown in figures C.1 a), C.2 and C.4, is adequate.

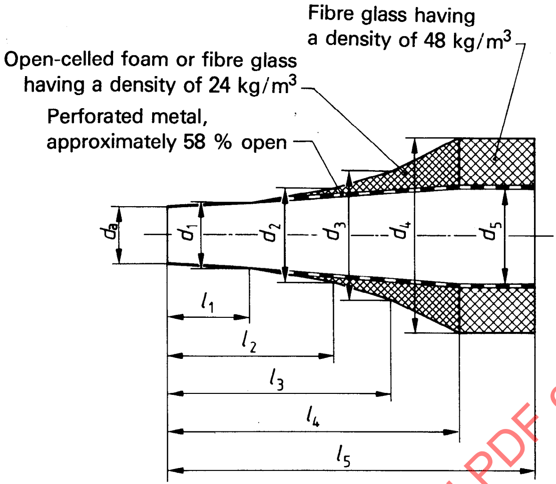
C.4 Since the inlet of the anechoic termination and the outlet of the duct form a smooth transition, the integral diameters are equal at the point of connection, as shown in figure C.1, anechoic termination a). All anechoic termination dimensions are given in terms of the internal diameter d_1 of the outlet of the duct. Scaling to diameters other than those tested should only be done to a limited degree, however, because the ratio of wavelength to dimensions will be changed. The outer skin of the termination may be made of any material having sufficient strength to retain its dimensional characteristics.

In the anechoic termination shown in figure C.1 a), the aerodynamic passage through the centre of the horn is outlined by perforated metal having about 58 % open area. Particular attention should be paid to the smoothness of the transition at d_1. The volume between the perforated metal and the conical sections of the horn is filled with open-celled foam or fibre glass of density approximately 24 kg/m^3. The remaining cylindrical volume at d_4 is filled with fibre glass of density approximately 48 kg/m^3.

C.5 If transitions are to be used between the test duct and the anechoic termination, the transition is considered part of the anechoic termination, i.e. the anechoic termination together with the transition has to meet the requirements of 4.2.5.

C.6 Examples of throttling devices are given in figure C.5.

In figure C.5 a throttling device is described which consists of nine exchangeable screens which provide gradually increasing flow resistance.

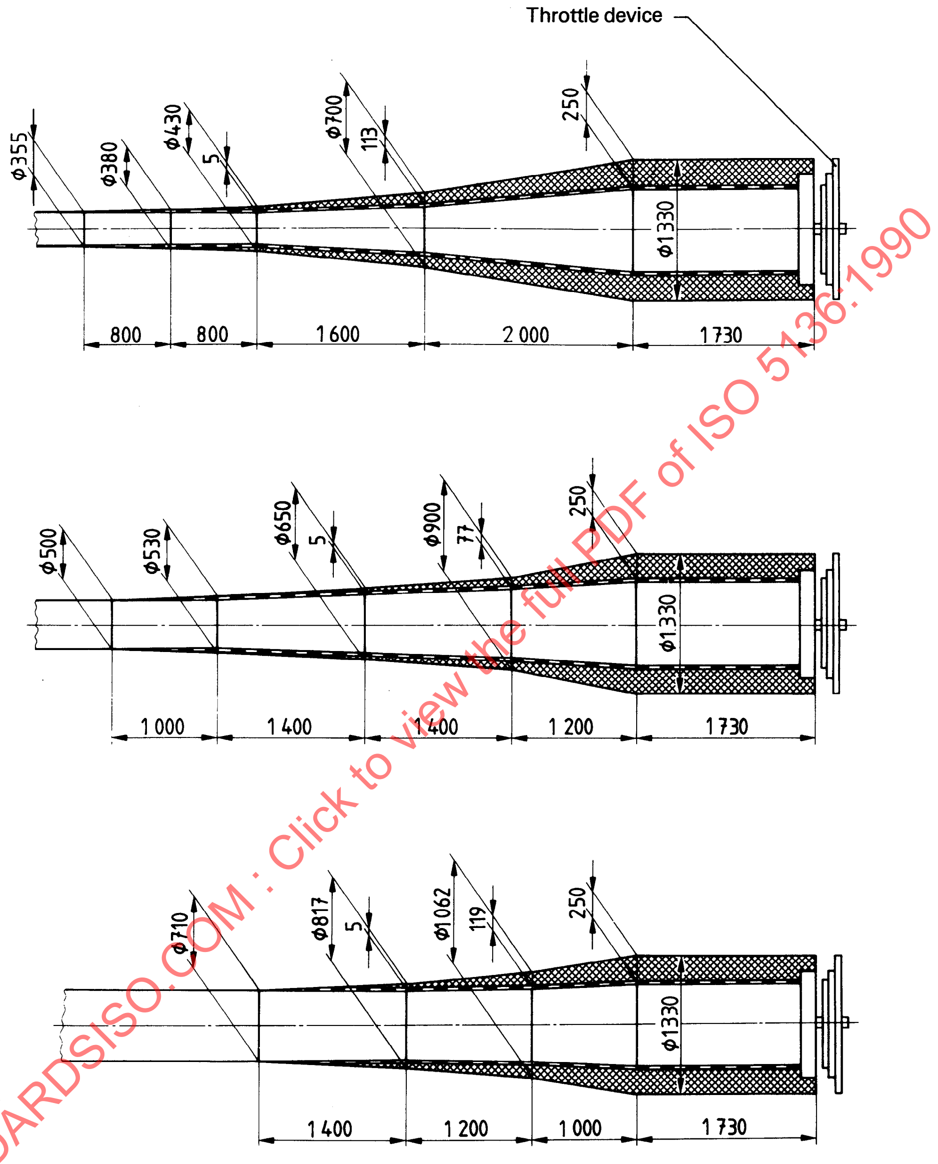


Duct internal diameter, d_a			
d_1	1,15d	l_1	1,44d
d_2	1,64d	l_2	2,89d
d_3	2,25d	l_3	3,89d
d_4	3,44d	l_4	5,11d
d_5	1,67d	l_5	6,44d

a) Anechoic termination tested for diameter d_a = 0,46 m (see [9])

Figure C.1 — Examples of anechoic terminations

Dimensions in millimetres



NOTE — The lining is of expanded polyurethane foam of density 32 kg/m³.

b) Three catenoidal designs of anechoic termination

Figure C.1 — *(concluded)*

Dimensions in millimetres

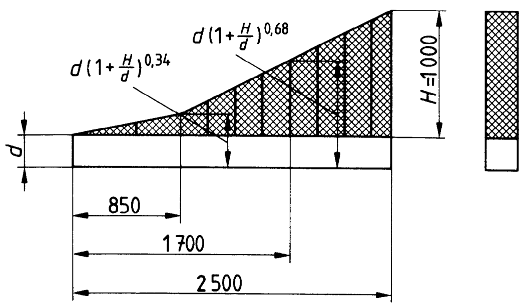
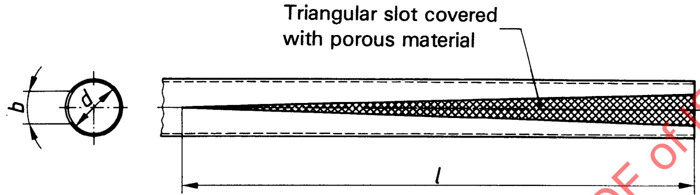


Figure C.2 — Example of one-sided anechoic termination
(tested for $d \leqslant 250$ mm, see [10]; for $d > 250$ mm, two-sided anechoic terminations may be used, see [14])



$l = 9d$
$b = 0{,}6d$
Flow resistance ≈ 400 Ns/m^3 ($\approx 1\varrho c$)

Figure C.3 — Example of anechoic termination
(tested for $d \leqslant 0{,}3$ m, see [6])

Dimensions in millimetres

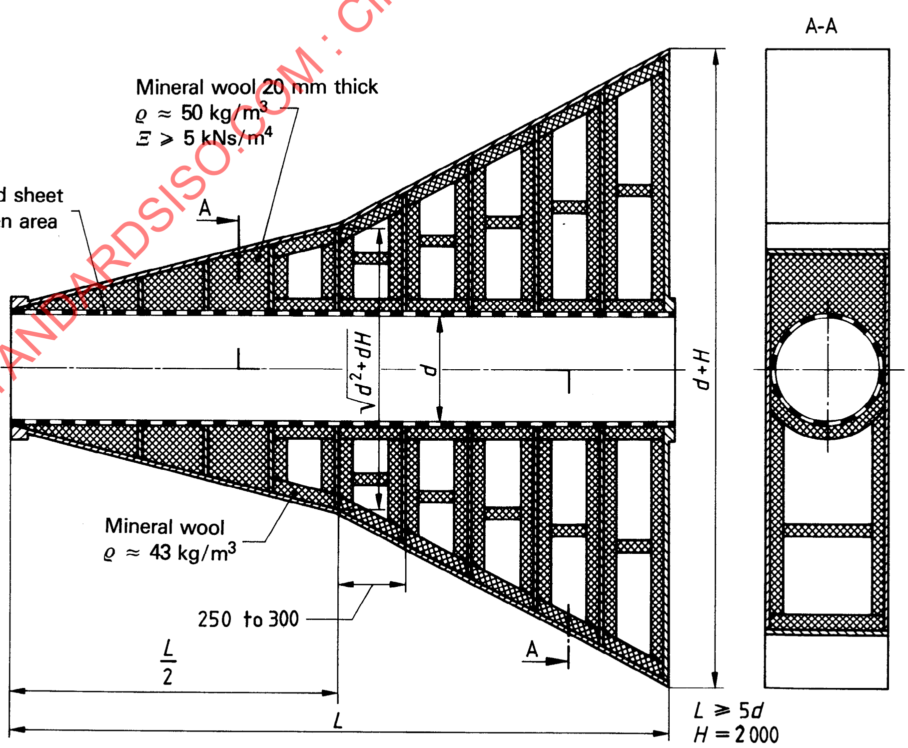
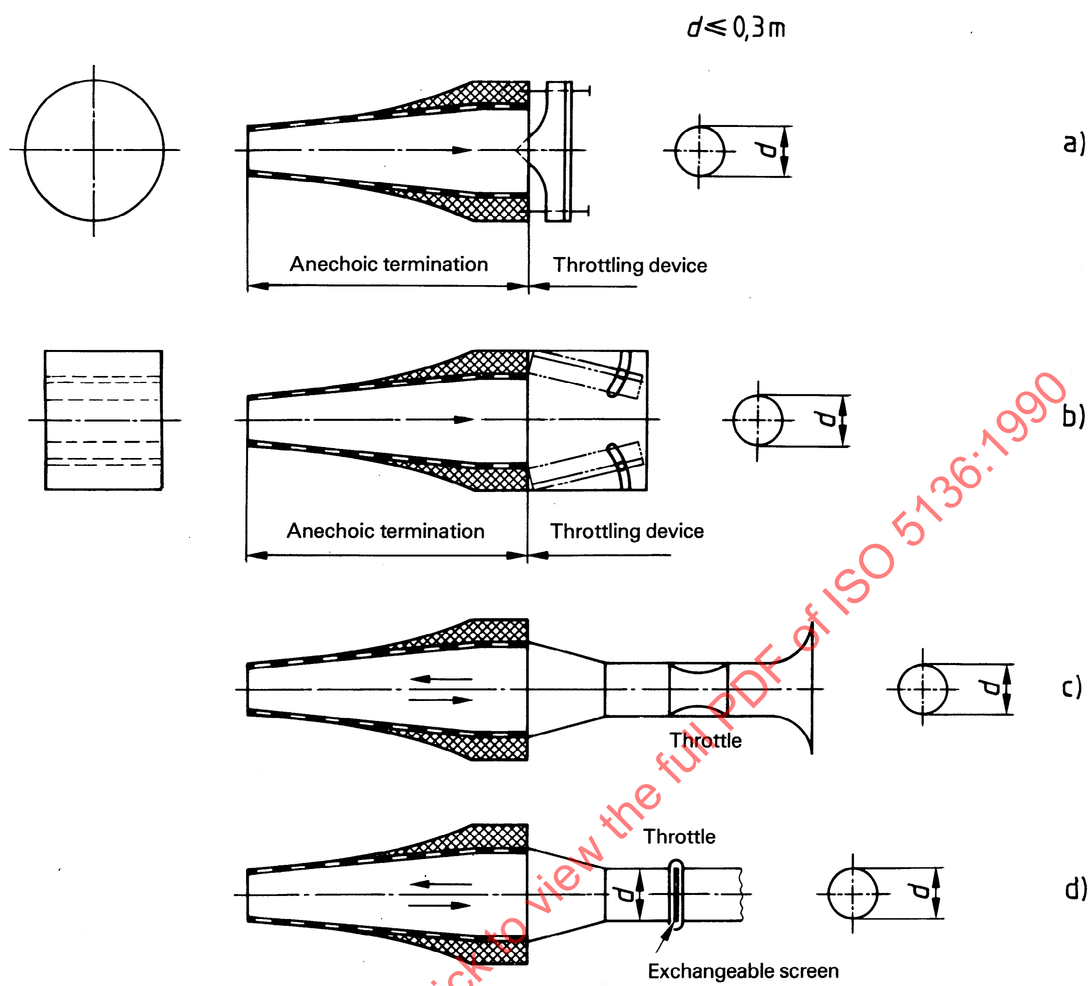
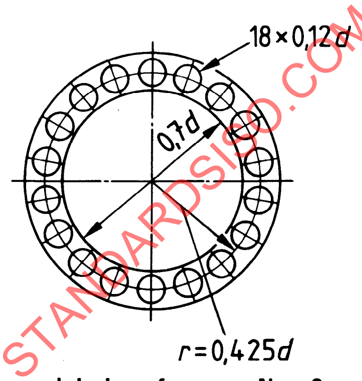
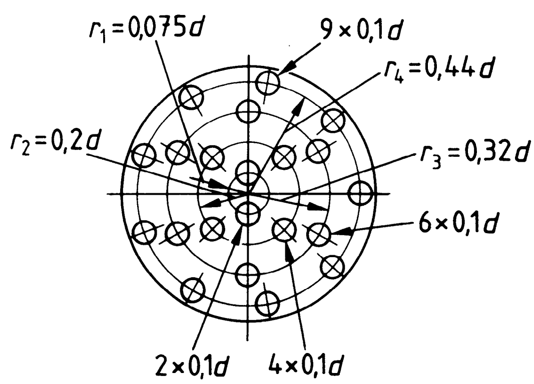


Figure C.4 — Example of two-sided anechoic termination
(tested for $d = 400$ mm, $d = 500$ mm, see [18], and for $d = 630$ mm)





General design of screens Nos. 2 and 3
(Example shown is screen No. 3)



General design of screens Nos. 4 to 10
(Example shown is screen No. 7)

Design of screens

Orifice position in radius	Screen number								
	2	3	4	5	6	7	8	9	10
	Number of boreholes at radius r_i								
r	18	9	—	—	—	—	—	—	—
r_1	—	—	3	3	3	2	2	2	—
r_2	—	—	10	10	5	4	5	4	—
r_3	—	—	16	12	8	6	7	4	—
r_4	—	—	24	16	12	9	—	—	—

Figure C.5 — Examples of throttling sections

Annex D
(informative)

Evaluation of performance of anechoic terminations

D.1 This annex gives an example of the determination of the pressure reflection coefficient. Calculate the pressure reflection coefficient, r_a, from a measurement of the difference ΔL between the maximum and minimum sound pressure levels occurring in the duct as a result of the standing wave formed by the incident and the reflected plane waves at each centre frequencies of the frequency bands, using the formula

$$r_a = \frac{10^{\Delta L/20} - 1}{10^{\Delta L/20} + 1}$$

D.2 It is recommended that the pressure reflection coefficient be measured from 50 Hz to the cut-off frequency, f_o, of the first cross-mode, which is given by the formula

$$f_o = 0{,}586 \frac{c}{d}$$

where

c is the speed of sound, in metres per second;

d is the diameter of the throat of the termination, in metres.

NOTE — Only at frequencies lower than f_o can one be sure that only plane waves exist in the duct.

D.3 A procedure for evaluating the anechoic termination performance is given below.

a) After connecting the test duct to the anechoic termination, mount a high-quality loudspeaker in a baffle which covers the inlet of the test duct.

b) Make provision for moving a microphone without the sampling tube along the full length of the centreline of the measurement duct.

c) Apply a pure tone signal from an audio oscillator to the loudspeaker, via an amplifier if necessary, for the centre frequency of the one-third octave band.

d) Filter the microphone signal through a narrow-band or a one-third octave band analyser and then apply the filtered output signal to a graphic level recorder.

e) Move the microphone along the axis of the measurement duct to measure the difference between the maximum and minimum sound pressure levels.

f) Take the difference between the maximum and minimum sound pressure levels (ΔL) and insert them into the formula in D.1. Compare the reflection coefficient r_a obtained with the values listed in table 3.

g) Repeat steps c), d) and e) for the centre frequencies of the one-third octave bands between 50 Hz and f_o.

h) If the anechoic termination is fitted with a means of flow rate control, repeat step g) with the throttle set to give maximum flow rate and then to give minimum flow rate.

i) If the graphic level recorder mentioned in d) is not available, manual recording of the maximum and minimum sound pressure levels is permitted.