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DESIGN OF TERMINATING DUCTS FOR FAN NOISE TESTING

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ABSTRACT
A new ISO Standard (ISO 13347) is being prepared by Technical Committee ISO/TC117/WG2 Industrial Fans - Acoustics, which describes different methods for the determination of fan sound power levels under standardized laboratory conditions. The measurement procedures cover the following fan installations: free inlet/free outlet, free inlet/ducted outlet, ducted inlet/free outlet, ducted inlet/ducted outlet. The sound levels are measured either in the duct, according to a procedure described in ISO 5136, or outside the duct. A duct in which the sound pressure is to be measured for determination of the in-duct sound power is called a "test duct". Such a duct has to be terminated with a good anechoic termination to minimize duct end reflections which contaminate the pressure signals measured in the duct. On the other end, a duct in which no sound measurements are to be made is called a "terminating duct". This duct still needs to be fitted with an anechoic termination in order to specify a standardized acoustic load impedance, as it is now well known that the sound power level radiated by a fan depends on the acoustic impedance of the ducts connected to the fan. The performance of the anechoic termination of a terminating duct does not need to be as high as that of a test duct. Standard specifies that below 160 Hz the maximum permissible pressure reflection coefficients for a terminating duct is twice higher than those of a test duct. This paper presents results of tests carried out for defining "simplified" anechoic terminations for terminating ducts, which are less expensive and bulky than true anechoic terminations. This simplified termination is a set of simple cylindrical silencers in series with stepped outer diameters. It is shown that only two silencers suffice to conform to the reflection coefficients of the standard for duct diameters between 400 and 800 mm and a single silencer is suitable above 800 mm. The influence of the termination configuration on the fan sound power level measured on the side opposite to the terminating duct is also shown. This paper could be cited as a reference in the new standard.

1 - INTRODUCTION
This paper falls within the framework of the ISO 13347 draft for acoustical fan testing. The purpose of this standard is to define laboratory condition test methods for the determination of fan sound power levels radiated by free inlet, free outlet and fan casing. The project describes three test methods adapted to fans which draw on general acoustic standards ISO 3743, ISO 3744 and ISO 9614 namely, the Reverberant Room Method, the Enveloping Surface Method and the Sound Intensity Method. In parallel with this project, ISO 5136 details the procedure for measuring the in-duct sound power of ducted fans [1].
These different test methods enable simultaneous measurement of the aerodynamic and acoustic fan performances, the aerodynamic performances being determined in accordance with ISO 5801 [2]. In the description of these methods in Section 2 we will see that the test ducts must be anechoically terminated in order to impose well defined duct acoustic impedances. The aim of this paper is to show the influence of an anechoic termination at the end of a duct on the sound power spectrum measured on the opposite side and to suggest geometrical designs for the terminations based on commercially available silencers which are less expensive and less bulky than conventional anechoic terminations.

2 - ACOUSTIC TEST METHODS FOR FANS
In line with international terminology four fan installation categories can be defined:

- type A: free inlet, free outlet
- type B: free inlet, ducted outlet
- type C: ducted inlet, free outlet
- type D: ducted inlet, ducted outlet.

Since the inlet noise level is different from the outlet noise level and the level radiated by the fan casing, 12 different noise levels can be distinguished for the same fan. In practice, interest is generally limited to a much smaller number of configurations for any given fan. The free inlet or outlet levels are measured in accordance with one of the three methods given in ISO 13347, whereas the in-duct levels are determined as laid out in ISO 5136 [1]. In the case of small fans, the method using a mylar plenum, as described in ISO 10302, can also be applied.
Figure 1, taken from [1], shows the diagram of standardized type-B test duct assembly. The components below can be seen in the diagram by following the direction of flow:

- the fan undergoing testing,
- the common part as defined in ISO 5801, consisting of a flow straightener which makes the flow axial by breaking up the swirl at the fan outlet, which enables the measurement of the fan pressure rise as well as improving the in-duct noise measurement [1],
- a test duct in which the acoustic pressure measurements are carried out,
- an anechoic termination,
- a flow measurement and control system (orifice plate for instance).

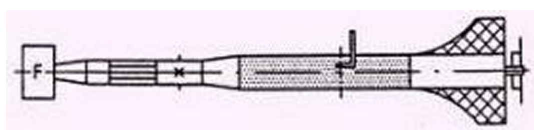

Figure 1: Fan test arrangement.

The standards distinguish two types of ducts, test ducts and terminating ducts. A test duct (figure 1) is a duct in which sound pressure measurements are performed with the aim of determining the fan in-duct sound power in accordance with ISO 5136. A terminating duct is a duct which is used for the sole purpose of conveying air and which is not used for any acoustic measurements. The test duct must be fitted with a good-quality anechoic termination to minimize the duct-end reflections which would distort the in-duct sound pressure due to the interference between the direct and reflected waves. The terminating duct must also be equipped with an anechoic termination in order to impose a standard acoustic impedance on the duct and so prevent the sound power level radiated by the fan inlet or outlet on the opposite side of the terminating duct depending on the duct reflection coefficient. However, the sound attenuation performance of the anechoic termination of the terminating duct does not need to be as efficient as that of the test duct, as will be seen in the following section.

3 - INFLUENCE OF THE REFLECTION COEFFICIENT OF THE TERMINATING DUCT

The sound power radiated by the fan inlet or outlet depends on the acoustic impedance of the inlet and outlet circuits. By using a simplified 2-port model, Baade [3] showed that the sound power at a fan outlet, assimilated to a dipole source, is given by:

$$W_2 = \frac{\Delta p^2 \mathrm{Re}\left(Z_2\right)}{\left|Z_1 + Z_f + Z_2\right|^2} \tag{1}$$

where

- W: sound power
- Δp: source strength

- Z: complex acoustic impedance (subscript 1 for the inlet, 2 for the outlet)
- Z_f : fan internal impedance
- Re(): real part of complex impedance.

This model, which has been subsequently improved (e.g. see [4]), clearly shows the role that the fan inlet and outlet duct impedances have on the power radiated at the outlet, or the inlet if subscripts 1 and 2 are reversed in (1).
To illustrate this point, we have used an installation like the one shown in Figure 1 to compare the differences in sound power measured at the free inlet of a fan both with and without an anechoic termination being fitted to the outlet duct. Figure 2 shows the difference in sound power in one-third octave band between the levels with and without an anechoic termination for two types of fans, axial and centrifugal mounted on a 400 mm duct. The differences in dLw are significant essentially at low frequency (f $<$ 400 Hz), but they are not higher at the blade passage frequency (315 Hz for the axial fan and 400 Hz for the centrifugal fan) than at the other frequencies.

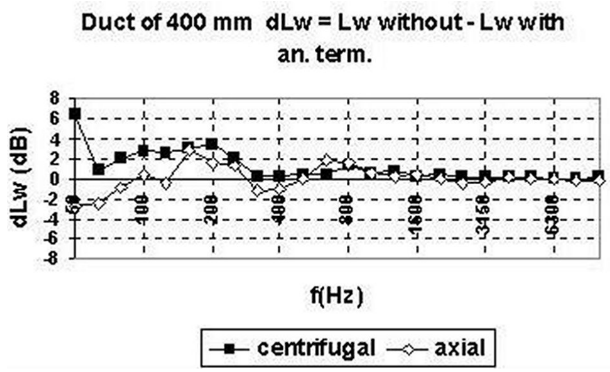

Figure 2: Influence of an anechoic termination at the fan outlet on the inlet sound levels.

When a commercially available cylindrical silencer of 2D length is inserted at the end of a terminating duct the differences in dLw, in comparison to the configuration with an anechoic termination, are less than those observed for the duct without silencer (figure 3).

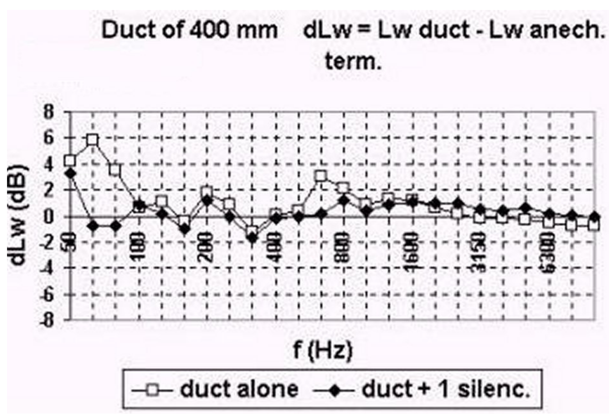

Figure 3: Influence of the outlet duct on the fan inlet levels.

ISO 5136 and ISO 13347 specify the maximum permissible values with respect to frequency of the pressure reflection coefficient R for both the test and the terminating ducts. These values are given in Table 1.

One third octave frequency (Hz)	Maximum pressure reflection coeff	
	Test duct	Terminating duct
50	0,4	0,8
63	0,35	0,7
80	0,3	0,6
100	0,25	0,5
125	0,15	0,3
160	0,15	0,3
> 160	0,15	0,2

Table 1: Maximum permissible values for the pressure reflection coefficient of anechoic duct terminations.

In order to verify if a duct equipped with a simple cylindrical silencer could, if necessary, satisfy the conditions of anechoicity for terminating ducts specified in Table 1, some measurements of coefficient R were made, without any flow, in different duct configurations using Chung and Blaser's two-microphone method [5]. A point not mentioned by theses authors, and which must be taken into consideration when measuring the reflection coefficient (or impedance) of a duct with a minimum of accuracy using this technique, is the extreme sensitivity of the results to the radial position of the two microphones mounted on the wall of the duct. The microphones must be perfectly flush with the wall (to within a few tenths of a mm), otherwise the results will be incorrect in the $(50 - 80$ Hz) frequency range. As mentioned by Chung and Blaser, the systematic use of the microphone switching procedure is also advisable in order to eliminate electrical phase shift problems between the two microphone channels and one also must ensure that there is an adequate signal/noise ratio.
Figure 4 compares the average values of R for a duct of 400 mm diameter in each 1/3 octave frequency band between 50 and 400 Hz for the duct alone, the duct fitted with a cylindrical silencer (2D length, 70 mm thick sound absorbent material) and the duct with an anechoic termination. It can be seen that the values of R obtained with the silencer are much higher than the limit values given in Table 1 for terminating ducts. This excludes the use of a single silencer as a simplified anechoic termination for 400 mm terminating ducts.

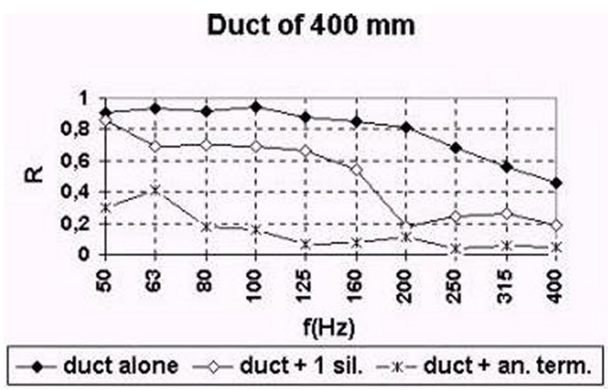

Figure 4: Pressure reflection coefficients D=400 mm.

In the case of an 800 mm duct on the other hand, a single silencer of 2D length and fitted with 100 mm thick sound absorbent material gave values of R which satisfy the standard limits for terminating ducts at practically all frequencies (Figure 5). Large diameter open ducts (D $\geq$1600 mm) comply with the standard without the need for a silencer.
To further the investigations, measurements of the reflection coefficient were made on a 400 mm duct equipped with several silencers in series, with a gradually increasing outer diameter and a constant inner diameter equal to that of the duct (Figure 6). These silencers, like all those tested in the project, had an inner perforated sheet metal wall, a layer of rock wool with a density of about 60 kg/m^3 and an outer metal casing.
Figure 7 compares the values obtained with one, two and three silencers in series respectively. It can be seen that with two silencers, and even more so with three, R complies with the standard at all frequencies. This enables, for 400 mm diameter terminating ducts and larger, the recommendation of a simplified anechoic termination consisting of 2 standard commercially available cylindrical silencers in series. The

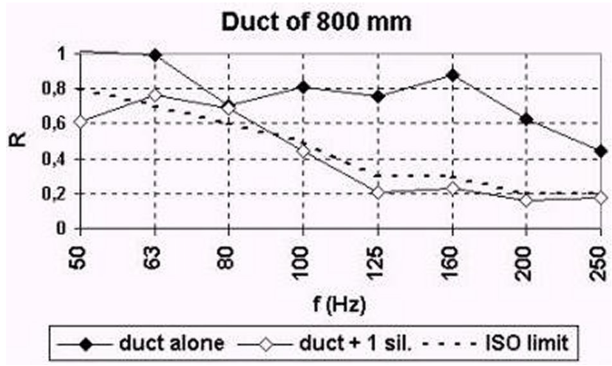

Figure 5: Pressure reflection coefficient D = 800 mm.

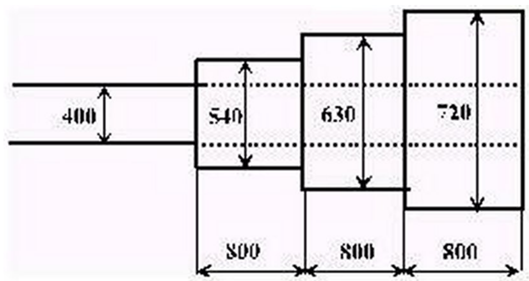

Figure 6: Silencers in series with the same inner diameter.

choice of silencer size can be based on the information given in Figure 6 for a 400 mm duct. Additional tests have shown that the inner diameter of the silencers in series must be equal to the diameter D of the duct because, in the opposite case, the values of R exceed the standard limits in some frequency bands.

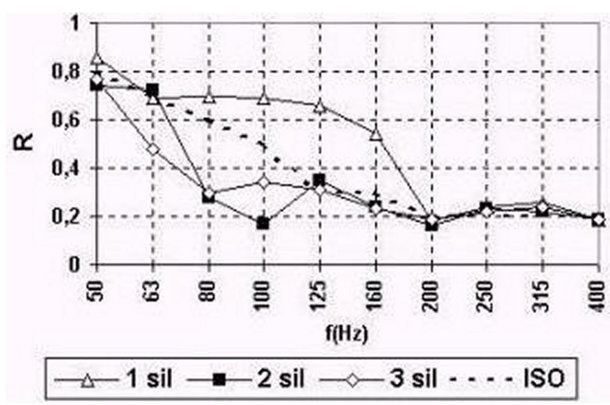

Figure 7: Pressure reflection coefficients of a 400 mm duct with silencers in series.

4 - CONCLUSIONS

The experimental study described here was carried out within the framework of the ISO 13342 draft for acoustical fan tests. It has shown the necessity of installing an anechoic termination at the end of the terminating duct to prevent the sound waves reflected by the extremity of the duct from modifying the sound power emitted by the fan on the opposite side at low frequencies. The study has enabled different combinations of simplified anechoic terminations to be defined which are much less expensive and less bulky than real anechoic terminations, and whose reflection coefficient values as a function of frequency comply with the limits specified in the standard. The recommended configurations as a function of the terminating duct diameter are as follows:

- D $\geq$1600 mm: open duct without silencer

- 800 $\leq$D < 1600 mm: a silencer of 2D length
- 400 $\leq$D < 800 mm: two stepped silencers in series of 2D length and constant inner diameter
- D < 400 mm: full anechoic termination.

Experience has shown that it is possible to include an airflow control and measurement system, such as an orifice plate, in addition to the simplified anechoic termination without significantly increasing the reflection of the sound waves from the end of the duct. This is obviously not the case for an open duct without a silencer. These recommendations will be integrated into the text of the future ISO 13347 as well as that of ISO 5136 which is currently being revised.

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