On acoustic fan installation effects : summary of work at MWL

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The bulk of the work done on fan installation effects has been based on experimental investigations and has focused on small or medium sized fans and low frequency effects. The studies concern both installation effects caused by ductwork coupled to the fan, i.e., acoustic loading, as well as the effect of in- or outflow conditions.

To understand and analyse noise problems it is essential to be able to characterise sources of sound. This involves determining their source strengths but also how they interact with their surroundings. One important tool in analysing acoustic loading, caused by the effect of placing the source in a duct, is experimental source characterisation [1,2]. The goal of source characterisation is to provide a complete and independent source model, that fully describes how the source interact with the receiving system and does not depend on the properties of the receiver. In other words to give source data that are not affected by acoustic loading effects. This is unlike the standard methods that exist and use sound power measured at a given load, normally reflection free, to characterize a source. Normally the acoustic load the source experience when installed, at least for low and intermediate frequencies, is quite different and affected by standing wave effects. A complication in dealing with noise generation from fans is also that inflow and to some extent outflow conditions can effect the sound generation. The acoustic power generated by fans can be strongly influenced by flow related installation effects as pointed out by several authors, e.g. [3]. This fact makes measurement of the acoustical properties of fans more complex than for many other machines. The source characterization methods developed by us are based on tests using different acoustic loads applied to the fan. There is of course a risk that this will change the source data, which are especially sensitive to changes in the inlet flow conditions.

In this paper procedures for determining source data in the form of acoustic multi-ports is first described. This characterization suitable for low and intermediate frequencies (up to say max 10 propagating modes) gives a source description independent of the acoustic loading. Using this kind of source data acoustic installation effects are then investigated for two axial fans. Secondly the effects of inflow disturbances, in particular turbulence ingestion, is investigated for an axial fan. Finally, a method to investigate the effect of in- and outflow conditions for small axial or mixed flow fans, using acoustically transparent ducts mounted to an ISO 10302 fan test rig, is suggested.

Source characterisation

This section gives an overview of the field of low frequency experimental in-duct source models for ventilation fans. The simplest model is the one-port model, which can be used in the plane wave region if one side of the fan is considered as fixed and the other side is duct mounted. The two-port model can be used in the plane wave region if both sides are duct mounted. The source data can be used to analyse the coupling between the ducts on either side of the fan and the characteristics of the source. The N-port model can be used either in the plane wave range if there are more than two inlet/outlet ports or it can be used for higher order modes fore a one port fan.
In the low frequency domain an acoustic one-port can be completely described by a source strength p_+^s and a source reflection coefficient R_S

$$p_+ = R_s p_- + p_+^s \,, \tag{1}$$

where P_+ and P_- are the travelling pressure wave amplitudes for the plane wave in the positive/negative direction at the reference cross-section (see Figure 1)[4]. In the literature the source model for 1-ports is often expressed in terms of a source strength (P^S or q^S) and a source impedance (ζ_S)

$$p = p^s - Z_o \zeta_s \, q \,, \tag{2}$$

where P_+ is the source pressure, p and q are acoustic pressure and volume velocity, respectively, and Z_o is the characteristic impedance of the fluid. The volume velocity q is defined positive in the outward direction from the source and all quantities are referred to a reference cross-section.

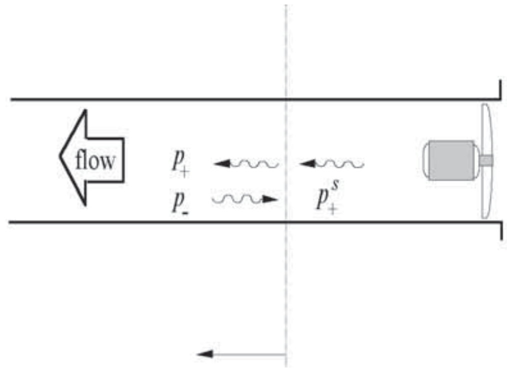

Fig. 1: An in-duct source modelled as an acoustic one-port

For fans the acoustic coupling between the inlet and the outlet and changes in the conditions on both sides must normally be considered, which means that the two-port model must be used [5-8]. If the travelling pressure wave amplitudes P_+ and $P\_$ are chosen as state variables the relationship between the input and the output can be expressed using a scattering-matrix form. For an active acoustic 2-port (see Figure 2) it can be written as

$$\begin{bmatrix} p_{a+} \\ p_{b+} \end{bmatrix} = \begin{bmatrix} \rho_a & \tau_a \\ \tau_b & \rho_b \end{bmatrix} \begin{bmatrix} p_{a-} \\ p_{b-} \end{bmatrix} + \begin{bmatrix} p_{a+}^s \\ p_{b+}^s \end{bmatrix} , \qquad (3)$$

or $$p_+ = Sp_- + P^S, \qquad (4)$$

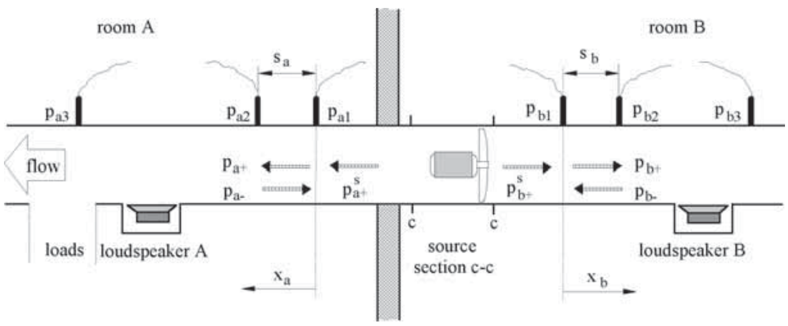

Fig. 2: Test rig for two-port source measurements.

The one-port and two-port models are only valid in the plane wave range. To extend the experimental source characterisation methods to the case that a number of modes are propagating in the ducts the N-port source model has been suggested and also applied to an axial fan [9].

Acoustic loading

Two examples of the effects of acoustic loading will be shown in this section. In the first example measurements were made of the source data for an axial flow fan using the 1-port model [4] and the 2-port model [7]. The fan used for the experiments was an axial flow fan (Fläkt/FDC-040-1) with six blades. The diameter of the fan duct was 0.40 m and the length of the fan duct section (c-c in Figure 2) was 0.50 m. The cut-on frequency of the first higher order mode will for this duct diameter be approximately 500 Hz. From the source data the sound power level difference between the maximum sound power and the emitted sound power for an anechoic load was calculated. The result for the 1-port measurements is shown in Figure 3 for two different rotational speeds, corresponding to two different flow Mach numbers (0.014 and 0.028). The fan was mounted in a wall without any inlet duct in this case. The level difference is typically between 1 and 7 dB.

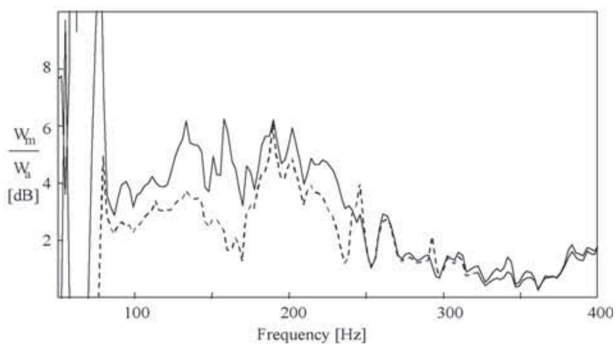

Fig. 3: Maximum emitted sound power on the outlet (a) side normalized using the sound power emitted with an anechoic load, calculated from 1-port source data measured on an axial flow fan.
————, 1430 rpm;------------- , 2850 rpm. [10]

The second example is from the acoustical analysis of a 6-blade road tunnel fan, a so-called jet fan, in the plane wave frequency domain [11,12]. This type of fan is mounted in a short duct typically 3-4 meters long. The objective of the experimental investigation was to fully characterize the aeroacoustic response of the fan running in different aerodynamic and acoustic configurations consisting of: non-uniform steady flow, incoming turbulence and different fan locations, see Figure 4. Hot-wire anemometry was used for the flow measurements. During the aerodynamic and turbulence measurements, simultaneous acoustic sound power measurements were made using ISO 3741-3742.

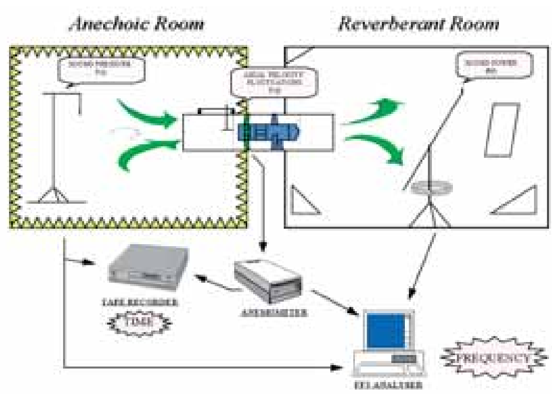

Fig. 4: e Setup used for the aerodynamic and acoustic measurements

As part of this study a theoretical model for the sound generation for the jet fan was developed. One objective of the project was to investigate the effect on sound generation of mounting the fan at different positions within the duct. Figure 5 shows the difference in radiated sound power when the fan is situated at a position 14.6% of the duct length from the center compared to the when it is situated in the central position. Both theoretical and experimental results are shown. It can be seen that the difference between the worst and best mounting position was 8-10 dB.

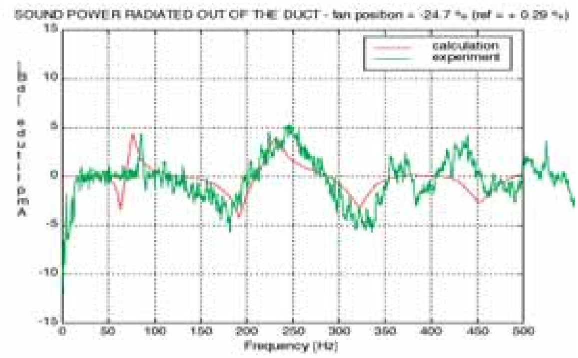

Fig. 5: Acoustic loading effect; comparison theory / experiment

Effect of flow conditions – turbulence ingestion

As mentioned in the previous section the work on the 6-blade road tunnel ventilation fan [11,12] included an analysis of the primary fan sound generating mechanisms. A preliminary study showed that disturbed inflow conditions, i.e. turbulence ingestion and non-uniform inflow, were major sound generating mechanisms. To change the turbulence characteristics different turbulence grids were applied upstream of the fan, see Figure 6.

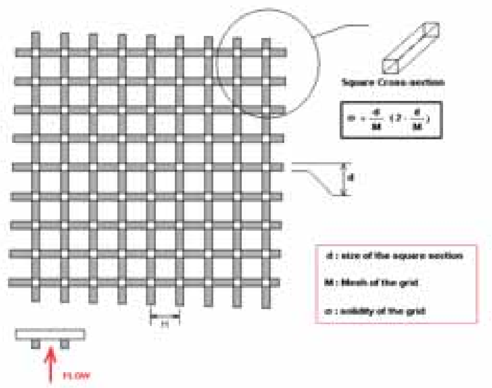

Fig. 6: Turbulence grid shape

Grids were made from square cross section bars with width 2 – 6 mm and mesh distance 10 – 30 mm, all with the solidity 0.44. The tested geometries were:

d = 2 mm and M = 10 mm – grid No2
d = 3 mm and M = 15 mm – grid No3
d = 4 mm and M = 20 mm – grid No4
d = 5 mm and M = 25 mm – grid No5
d = 6 mm and M = 30 mm – grid No6

The grids were mounted 38 – 58 cm upstream of the fan section. Measurements of the inflow turbulence characteristics upstream of the fan revealed that application of the grids significantly reduced the integral length scale, see Figure 7. Simultaneous sound power measurements showed a clear decrease in the tonal noise. Figure 8 shows the difference in sound power level without and with grid, for 5 different grids mounted 58 cm from the fan. From the results in Figure 8 it can be seen that the introduction of the grids significantly reduces the tonal sound generation while the broadband part is increased for some grids. The conclusion drawn is that the grids reduce the axial length scale of the turbulence and thereby the tonal sound generation.

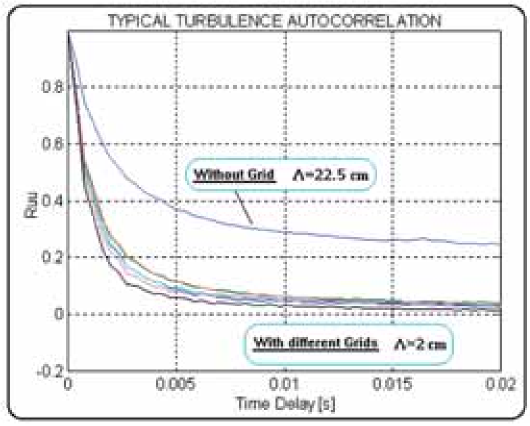

Fig. 7: Turbulence autocorrelation measurement without and with upstream mounted grids.

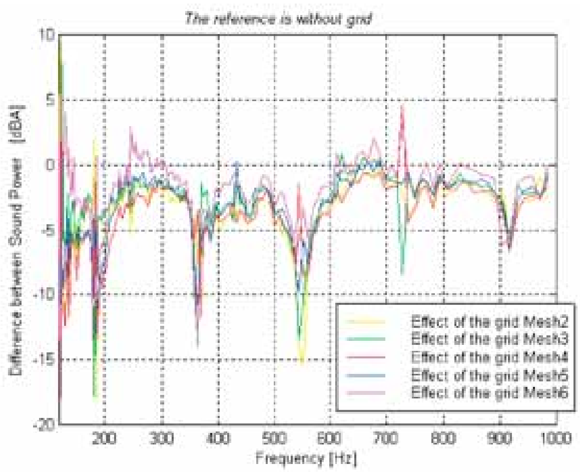

Fig. 8: Difference in fan sound power level without and with turbulence grids for 5 different grids

From the results in Figure 8 it can be seen that the introduction of the grids significantly reduces the tonal sound generation while the broadband part is increased for some grids. The conclusion drawn is that the grids reduce the axial length scale of the turbulence and thereby the tonal sound generation.

The use of acoustically transparent ducts

When measuring the source strength of a fan in a standard test-rig, it would be desirable to simulate the flow conditions present in the real application as close as possible, in order to account for any flow installations effects. During a recent EC-project [NABUCCO (GRD1-1999-10785)], it was suggested that this can be done by building a “copy” of the duct system of interest and attach it to the test rig [13]. The idea being that it is disturbances and geometrical constrictions “close” to the fan that matters, implying that the ducts need not to be very long but rather a few fan diameters.

The sound power of small axial fans is measured using a special rig described in ISO 10302. In order to account for the flow conditions, the previously mentioned ducts must be attached to the ISO 10302 test-rig. However, a duct system with acoustically rigid walls would not only affect the flow conditions but also the radiation impedance seen from the fan. To avoid this and still measure at acoustic free field conditions acoustically transparent ducts, see Figure 9, are created by using thin steel bars. These bars define a shape similar to the duct close to the fan and between the bars a thin plastic, the same as used in the ISO 10302 rig, is stretched in order to constitute acoustically transparent duct walls.

Fig. 9 : Left picture the ISO 10302 test rig with its plastic walls and a mounted fan; middle picture, duct section connected to the fan inlet; right picture, duct section connected to fan outlet. The ducts are similar to sections in a cooling fan installation for a cabinet with electronic equipment

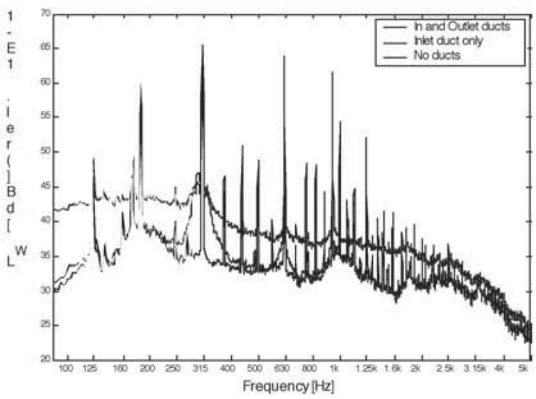

Fig. 10 : Example of sound power levels of an axial fan of mixed flow type with and without acoustically transparent ducts attached. The flow rate was kept constant

Figure 10 shows the measured sound power from a fan tested using this idea. As can be seen from the figure the effect of the inlet duct in this case is small, except for the haystack-effect around the blade passing frequency and its harmonics. However, the outlet duct seems to have larger effect on the sound generation in particular in terms of increased broadband levels. One explanation to this behavior, which is somewhat unexpected, is that a certain degree of flutter was observed in the outlet sections. Probably these sections should be made much shorter, say around one fan diameter.

Since for small axial or mixed flow fans one could argue that the main effect of an outlet section is to constrict the flow from radial expansion. Because the degree of radial expansion will affect the fluctuating momentum transport through the fan and thereby influence the fan dipole character.

Summary and conclusions

In the first part of the paper acoustic installation effects are studied in the low frequency, plane wave, region for two duct mounted axial fans. The two types of installation effects considered were acoustic loading, caused by changing the outlet duct or the fan position, and turbulent inflow structure. The acoustic loading was investigated using 1- or 2-port source models determined experimentally. For the axial fans studied maximum variations of 6-10 dB in the acoustic power at a single frequency was observed in the plane wave range. Concerning inflow turbulence the length scale was decreased by applying so called turbulence grids. This could reduce the tonal sound power generated by an axial fan with more than 10 dB. In the last part of the paper a procedure to estimate flow installation effects, based on acoustically transparent ducts, is proposed. The procedure is intended for small fans, which are tested using the ISO 10302 test rig. Our preliminary tests show that it seems possible to construct duct sections that simulate the effect of inflow conditions, without changing the acoustic radiation impedance experienced by the fan. This can be concluded from Figure 10, where all the peaks occurring are related to fan harmonics and no extra peaks due to standing waves appear. For the outlet duct tested the conclusion is to use a shorter duct piece, say around one fan diameter, to mainly check how changes in the radial flow expansion effects the source strength.

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