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NOISE RATING OF FANS ON THE BASIS OF THE SPECIFIC SOUND POWER LEVEL

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ABSTRACT

The aerodynamic noise output of fans of different designs are compared on the basis of the specific sound power level, i.e., the sound power level normalized in a certain way by the aerodynamic power of the fan. Using this concept, it is possible to compare different fan types over the whole range of their aerodynamic performance characteristics.

INTRODUCTION

This paper deals with fan selection from a noise point of view. The main criterion of fan selection is the aerodynamic duty described by volume flow $\dot{V}$ and total pressure rise Δp_t. In many practical situations a given amount of air has to be pumped through a given duct system, and then $\dot{V}$ and Δp_t are fixed. In this case there is generally only a limited choice of fan types that are suitable for the given task. However, there are also technical problems which can be solved with different combinations of $\dot{V}$ and Δp_t, and in these cases fans of different designs can be employed. For a example, a heat exchanger for a given heat transfer rate can be designed to have a large flow area and a small depth or, *vice versa*, a small flow area and a large depth. In the first case, the cooling fan would have to deliver a large flow rate at a low flow resistance, and in the second case a low flow rate against a high back pressure.

A direct fan noise comparison was attempted by Sigel et al (1980, 1981) who compared the sound power of six fans for a constant volume flow and for almost the same fan pressure. The drawback of this procedure is that the aerodynamic duties of the test fans are not exactly equal, that not all fans can be operated at their best efficiency point, and that the comparison can be made for only one operating condition.

In this paper, the noise characteristics of various fan types are compared using the concept of the specific sound power, i.e., the fan sound power normalized by its aerodynamic duty. In this way it is possible to compare different fan types over the whole range of their aerodynamic performance curve.

DEFINITION OF THE SPECIFIC SOUND POWER LEVEL

The sound power P generated by an aerodynamic sound source can be described using the following expression, see e.g. Goldstein (1976):

$$P \sim \varrho_0 D^2 U^3 \left(\frac{U}{a_0}\right)^m \qquad (1)$$

where D and U mean a characteristic length and flow velocity of the source, and ϱ_0 and a_0 are density and speed of sound of the fluid. The exponent m of the flow Mach number $Ma = U/a_0$ depends on the source type. In case of fans it is useful to choose impeller diameter D and tip speed U for the typical length and flow velocity. According to equation (1), the fan sound power is proportional to the aerodynamic power multiplied by a Mach number term which accounts for the fact that the acoustic radiation efficiency of an aerodynamic source increases with flow Mach number.

The first attempt to formulate a fan sound law for practical purposes was made by Madison (1949) who related the sound power emitted by the fan to the volume flow and the square of the fan pressure rise: $P \sim \dot{V}\cdot\Delta p_t^2$. Although this expression is incorrect from a dimensional point of view, it is the basis for the most frequently used formula to predict the sound power level L_W of a fan:

$$L_W = L_{WSM} + 10\cdot\lg\frac{\dot{V}}{\dot{V}_0} + 20\cdot\lg\frac{\Delta p_t}{\Delta p_{t0}} \qquad (2)$$

Here L_{WSM} is the specific sound power level which depends on the fan type and operating condition, and $\dot{V}_0 = 1\ m^3/s$ and $\Delta p_{t0} = 1$ Pa. Using the fan scaling laws ($\dot{V} \sim U\cdot D^2$, $\Delta p_t \sim \varrho_0 U^2$), Madison's fan sound law can be rearranged to give $P \sim \varrho_0{}^2 D^2 U^5$ from which it becomes obvious that a fixed tip speed exponent $\gamma = 5$ is assumed in equation (2) for all fan types.

Regenscheit (see the book by Eck (1962)) relates the fan sound power to the aerodynamic power loss of the fan multiplied by a Mach number term similar to that in equation (1):

$$P \sim \dot{V}\cdot\Delta p_t\cdot\left(\frac{1}{\eta_t} - 1\right)\cdot\left(\frac{U}{a_0}\right)^m \qquad (3)$$

η_t is the total fan efficiency. In logarithmic form equation (3) reads

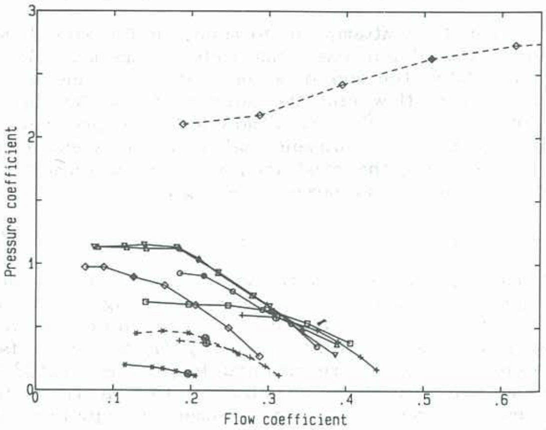
$$L_W = L_{WSR} + 10\cdot\lg\frac{\dot{V}}{\dot{V}_0} + 10\cdot\lg\frac{\Delta p_t}{\Delta p_{t0}} + 10\cdot\lg\left[\left(\frac{1}{\eta_t} - 1\right)\left(\frac{U}{a_0}\right)^m\right] \qquad (4)$$

Regenscheit set m = 2 für centrifugal fans and m = 2.5 for axial-flow fans, which with the fan scaling laws gives tip speed exponents of $\gamma = 5$ and $\gamma = 5.5$, respectively, for the two fan types. The term in parentheses that involves the fan efficiency is useful when one wants to predict a fan's sound power level. However for the purpose of the noise comparison it is omitted because otherwise a poorly designed low efficiency fan would be assigned a lower specific sound power.

The specific sound power level in the definition of equation (2) or (4) can be seen as a normalized fan sound power level or, in other words, as a sound power level for a unit fan aerodynamic duty. Hence, the specific scund power level is used here to compare the noise of different fan types. The two different formulations according to Madison and Regenscheit are used to ensure that the ranking of the various fans obtained is not a mere result of the way the specific sound power is defined. In the following, equation (2) and equation (4) with the efficiency term omitted are applied to the total, A-weighted and one-third octave band sound power levels.

EXPERIMENTAL DATA

The experimental data for the noise comparison are from Neise et al. (1986, 1987) and Hoppe & Neise (1987). Ten fans were measured using the standardized in-duct-method DIN 45 635 Teil 9 (1985) or ISO/DIS 5136.2 (1985). Anecoically terminated test ducts were connected to both inlet and outlet of each fan. The impeller diameters of the test fans ranged from 450 to 600 mm, and their tip speeds from 18 to 92 m/s. Figure 1 shows the performance characteristics of the test fans in non-dimensional form, i.e., in terms of the pressure coefficient $\psi = 2\Delta p_t/\varrho_0 U^2$ as function of the flow coefficient $\varphi = 4\dot{V}/\pi D^2 U$. The points of optimum operation are marked by filled or circled symbols. The performance curve of the scirrocco blower is only shown in part because it is almost flat over the range φ = 0.65-0.95. More details about the test arrangements and test fans are given in the original references and by Neise (1988).



	n 1/min	D m	U m/s	Z -	m -
Axial fan, OGV, airfoil blades	3000	0.45	70.7	24	2.5
Axial fan, OGV, airfoil blades	3000	0.45	70.7	12	2.5
Axial fan, no GV, airfoil blades	2925	0.60	91.9	8	2.5
Axial fan, OGV, airfoil blades	2943	0.50	77.0	12	2.5
Centr. fan, b.c. airfoil blades	1820	0.60	57.2	12	2.0
Centr. fan, b.c. airfoil blades	1600	0.51	42.7	12	2.0
Centr. fan, b.c. blades (flat)	1600	0.51	42.7	12	2.0
Centr. fan, flat radial blades	1800	0.51	48.0	15	2.0
Scirrocco blower (f.c. blades)	700	0.50	18.3	38	2.0
Mixed-flow fan (half-radial)	1000	0.45	23.5	8	2.0

Figure 1 Non-dimensional fan performance curves (n = impeller speed, Z = blade number)

RESULTS

Total Specific Sound Power Level

Figure 2 shows the specific sound power levels of the various fans as functions of the flow coefficient. The upper curves are according to Madison's (equation (2)) and the lower according to Regenscheit's definition (equation (4)). The total sound power is the sum of inlet and outlet duct power over the frequency range 50-10000 Hz. The points of optimum operation are marked as in Figure 1. With the exception of the axial fan without guide vanes, all fans show the well known U-shape distribution of the specific sound power level as function of the flow coefficient with their minima close to optimum efficiency operation.

If only the maximum efficiency points are considered, the centrifugal fans with backward curved blades are quietest, and the centrifugal fan

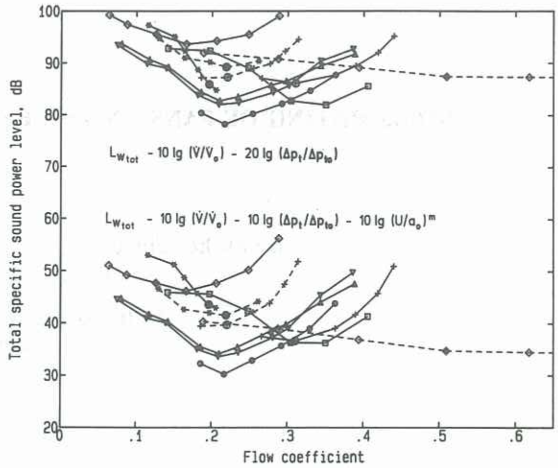


Figure 2 Total specific sound power level (legend as in Figure 1)

with radial blades is noisiest with a specific sound power level of 17 dB above the quietest. While the ranking of these two fan types is independent of the specific sound power level definition, this is not quite so in case of the other fans. In Madison's definition (lower group of curves), the scirrocco blower is a little quieter than the half-radial fan and all the axial-flow fans, but compared on the basis of Regenscheits definition it ranks behind the half-radial and one of the axial fans. The reason for this behaviour is that in Regenscheits definition volume flow and pressure rise are assigned equal influence on the specific sound power level, while in Madison's definition the pressure rise is given a much larger weight. Therefore the large pressure rise of the scirrocco blower helps make its specific sound power level according to Madison particularly small.

Over a fairly broad range of their performance curves, the axial-flow fans have, on average, higher specific sound power levels than the centrifugal fans with backward curved blades. This is particularly true at the respective points of optimum operation, and if the quietest ones in each of the two classes of fans are compared, the difference is between 6 to 8 dB, depending on the specific sound power level definition. Note that the maximum efficiency points of all axial and centrifugal fans compared in Figure 2 lie in a small range of the flow coefficient.

The two centrifugal fans with backward curved blades that are labelled with triangle symbols have almost identical geometries, except for the blade profile, i.e., airfoil blades versus flat blades. The first proves only marginally quieter in Figure 2 than the latter so that from an acoustic point of view flat blades seem to be just as good for centrifugal fans as airfoil blades

A-weighted Specific Sound Power Level

A-weighting reduces the level of the low frequency components, and the resulting effect on the overall noise level is the stronger the lower the fan speed. Therefore one has to be careful in discussing the acoustic performance of fans based on the A-weighted levels as shown in Figure 3, in particular when the fans to be compared were measured at different impeller speeds.

Because of its low impeller speed, the half-radial fans generates the lowest A-weighted specific sound power level of all fans, followed by the centrifugal fans with backward curved blades. As before, the ranking of the scirrocco blower depends on the specific sound power level definition.

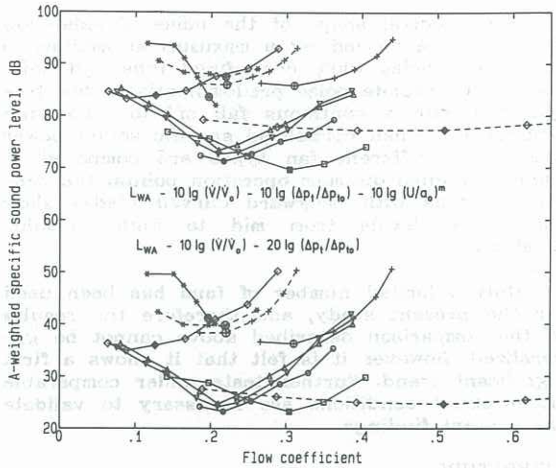


Figure 3 A-weighted specific sound power level (legend as in Figure 1)

With A-weighting, the specific sound power levels of axial and centrifugal fans differ even more than before, and this is not only due to the different impeller speeds but mainly to the fact that the spectral characteristics of the two fan types are entirely different: centrifugal fans radiate predominantly low frequency sound, while the noise spectra of axial-flow fans show a maximum in a medium frequency range where the effect of A-weighting is small. The result is that centrifugal fans appear quieter over almost the entire range of flow coefficients, and if only the quietest of two classes of fans are compared at their respective design points, the difference in the A-weighted specific sound power level is 13-14 dB.

Normalized Specific Sound Power Spectra

Figure 4 shows the normalized one-third octave spectra of the specific sound power of the various fans at their respective points of optimum operation using again the definitions according to Madison and Regenscheit. The sound power in each frequency band is the sum of inlet and outlet noise. The spectra are plotted versus the Strouhal number St = $(fD/U)\cdot(\pi/Z)$. In this presentation, the blade passing frequencies of all fans lie in the one-third octave band at St = 1.

The spectra of the centrifugal fans are highest at low frequencies and fall off towards higher frequencies, while the axial fans reach their maximum levels at mid frequencies. As a consequence, only in the very low frequency range are the specific sound power levels of the axial fan type lower than those of the centrifugal fans, but they are substantially higher at mid and high frequencies and in particular at the blade passing frequency and its harmonics. Only the centrifugal with radial blades which is known for its poor aerodynamic design generates specific blade tone levels as high as those of axial fans.

The spectrum of the vaneless axial fan peaks also at half the blade passing frequency because its eight blades are arranged unevenly in four pairs of two.

The spectral characteristic of the half-radial fan resembles that of centrifugal fans. The effect of the blade profile of centrifugal fans on the noise spectrum is as small as on the total noise. Comparing the curves with the triangle symbol, with airfoil blades only the high frequency random noise components are about 3 dB lower than with flat sheet metal blades.

The presentation in Figure 4 is useful when

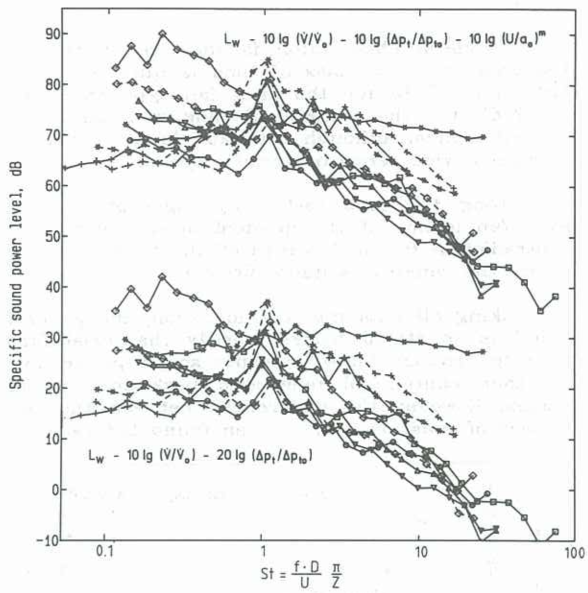


Figure 4 Non-dimensional specific sound power spectra (legend as in Figure 1)

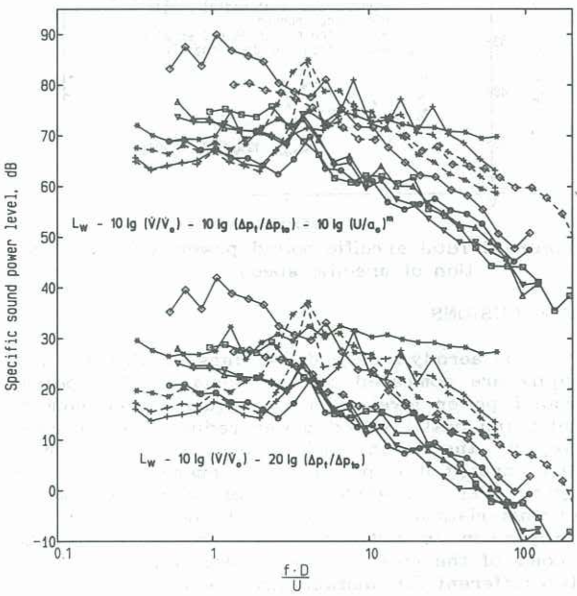


Figure 5 Non-dimensional specific sound power spectra (legend as in Figure 1)

comparing the levels of blade tones because due to the definition of the Strouhal number used they appear at integer values St = 1, 2, .. for all fans. For comparison of random noise components, however, it is more advantageous to plot the spectra as functions of f·D/U, i.e., without involving the number of impeller blades, see Figure 5. Here the large level differences between axial and centrifugal fans at medium and high frequencies are particularly evident.

Comparison with other Studies

In Figure 6 the total specific sound power levels of the various fans at optimum operation are plotted versus the specific speed $\sigma = \varphi^{0.5}/\psi^{0.75}$ (open symbols). Also included are results from Sigel et al. (1980, 1981) and Neise und Barsikow (1978) (filled symbols). The fan noise measurements in these two studies were made only in the fan outlet ducts. In order to compare the data with the total sound power levels discussed here, 2 dB were added (this means that the inlet sound power levels are assumed 2.3 dB lower than the outlet levels.

A general observation is that the scatter of the data for each class of fans is quite substantial, i.e., 5-7 dB for the axial fan type and even 10-12 dB for the centrifugal fans with backward curved blades, although the data do not cover an extremely wide range of specific speeds.

Among the fans tested by Sigel et al., the axial fan is one of the quietest ones, which is in contradiction to the findings of the present study where the ranking is quite different.

Taking all data into consideration, the general trend is as stated before, namely that axial fans tend to produce higher specific sound power levels than centrifugal fans with backward curved blades. However the differences between the two classes of fans are smaller than found before.

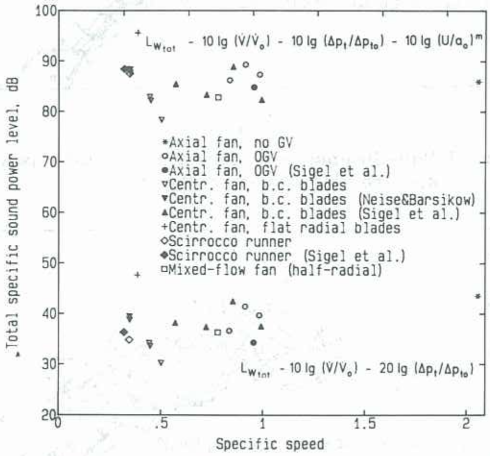


Figure 6 Total specific sound power level as function of specific speed

CONCLUSIONS

The aerodynamic noise of fans of different designs are compared on the basis of the specific sound power level, which is equal to the sum of inlet and outlet sound power reduced in a certain way by the aerodynamic power of the fan. With this concept it is possible to compare different fan types over the whole range of their performance characteristics. To ensure that the result of the comparison is not influenced too much by the choice of the specific sound power level definition, two different formulations are used.

Among the fan types tested, the centrifugal fans with backward curved fans generate the lowest specific sound power levels, followed by the mixed-flow fan (half-radial fan). The centrifugal fan with straight radial blades is the noisiest, as was to be expected. Airfoil shaped blades in centrifugal fans with backward curved blades have only a small advantage over flat sheet metal blades.

Over a fairly wide range of flow coefficients, axial fans have, on average, a higher specific sound power level than centrifugal fans with backward curved blades. At the respective points of optimum operation, the difference between the quietest in each class is 6-8 dB for the total and 13-14 dB for the A-weighted level. If the results of an earlier study by Sigel et al. (1980, 1981) are taken into account, the general trend is as stated before, however, the differences between axial and centrifugal fans become smaller.

The scirrocco blower ranks between half-radial and axial fans, depending somewhat on the definition of the specific sound power level.

The spectral shape of the noise of axial-flow fans is characterized by a maximum at medium to high frequencies while centrifugal fans and half-radial fans radiate noise predominantly at low frequencies with a continous fall off towards high frequencies. When normalized specific sound power spectra of different fan types are compared at their individual optimum operation points, the centrifugal fans with backward curved blades show the lowest levels from mid to high Strouhal numbers.

Only a limited number of fans has been used for the present study, and therefore the results of the comparison described above cannot be generalized. However it is felt that it shows a first significant trend. Further tests under comparable measurement conditions are necessary to validate the present findings.

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