NOISE SOURCE MECHANISMS IN AXIAL INDUSTRIAL FANS

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REDUCING NOISE, A DISCIPLINE IN DESIGN

Reducing noise in any systems like fan systems is not solely based on analysing noise sources. The whole system, including source, radiation, transfer and reception should be taken in account. This paper will only focus on the noise sources of a fan system and will therefore not be the complete solution to noise reduction in systems where fans are used. However, in well thought noise reducing design, an impression of the noise sources will be indispensable.

This paper is part of a study on noise in multi fan systems for Philips CFT. The types of fans in this study are axial cooling fans with moderate rotational velocity (figure 1).

Figure 1: Example of an axial fan [5].

In the exact determination of noise level of fan systems, measurements are often most reliable. The intention of this paper is therefore not to calculate or predict the exact noise produced by a system, but to give a general insight of the mechanisms of the noise sources. With this analysis, parameters are given to reduce the production of noise by these sources.

NOISE IN FAN SYSTEMS

In most fan systems, two dominant noise sources will be present. The first noise source is based on mechanical effects (bearings, motor, etc.). The second source is related to the aerodynamic effects. The mechanical effects are relatively small compared to the aerodynamically effects and will therefore be neglected in this analysis.

Aerodynamic noise sources are often the result of turbulence in the medium (air). The character of turbulence is chaotic. This is why this noise is most difficult to suppress. With the right adjustments in fan design and installation, one may reduce turbulence and thus the noise production of the fan system.

In general, one may say that the aerodynamic efficiency of the fan is a representative for the noise production of sources in the fan system [2]. In other words, with the existence of turbulence a fan produces more noise and is therefore less energy efficient (figure 2). In energetic terms, fans produce two types of pressure. The first and most important is *static pressure*. This pressure is the difference in air density (bar). The second and less powerful term is *velocity pressure*. Velocity pressure is kinetic energy, which is lost with the very first aerodynamic collision in a fan system. Static pressure is therefore most durable in energetic terms and is the most important component in fan efficiency.

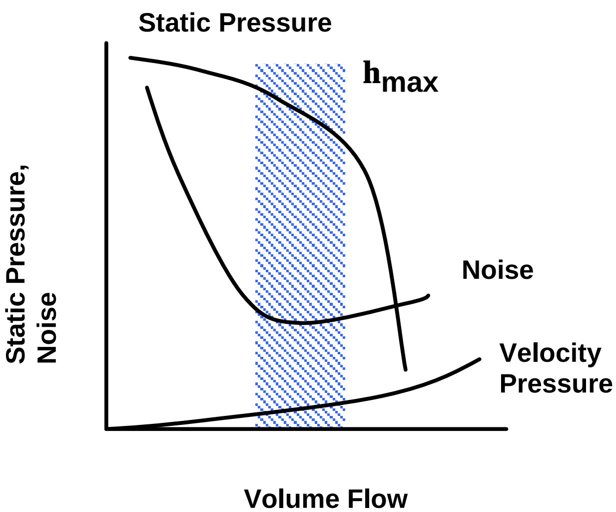

Figure 2: Efficiency and noise production

Noise of fan systems is generally experienced as a broadband and a single tone noise. This difference is mostly the effect of the mechanism of the source. Tone components are the result of a harmonic disturbance of the system. When a fan blade is continuously passing an obstacle at the inlet of the fan system, noise will occur at a single frequency. Altering the number of obstacles or the number of blades, the diameter or the rotational speed of the fan, will change this frequency. These changes do effect the systems efficiency and will therefore have to be studied thorough [6].

As the name of these sources reveals, broadband noise is spread across multiple frequencies. This is mostly caused by the chaotic behaviour of the source. In this source usually two main mechanisms play part. The first is called *vortex-shedding*. Vortex-shedding is the effect of the generated turbulence on about one third of the fan blade. Major parameter of this source is the fan blade tip speed (effects of 5^{th} and 7^{th} order). The other broadband noise source is based on *the matter of turbulence* in the airflow due to disturbances at the inlet and outlet of the fan. Both sources will be discussed below.

VORTEX-SHEDDING

The first and most dominant broadband noise source is vortex-shedding. This source will always be present in fan noise. The mechanism of this source is depicted below (figure 3).

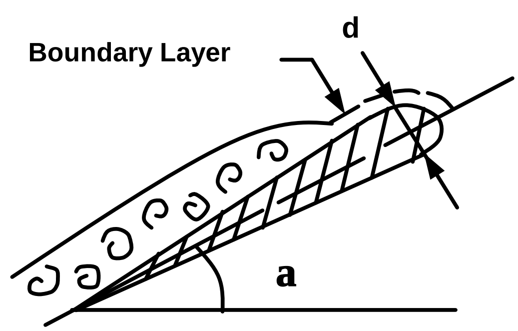

Figure 3: Vortex-shedding

The pressure of the laminar flow at the nose of the fan blade increases along the surface of the blade. At its highest pressure, the flow is lead in the bulky low-pressure air. This sudden change causes the air to turn in turbulent state. The area where this occurs is called the boundary layer. At the end of the boundary layer, the turbulent air will crash in the bulky air behind the fan blade and mix with the zero velocity media. This leaves a wake at the back of the fan. The presence of this boundary layer and the wake causes forces that are chaotic by character. These fluctuating forces are a source of acoustic energy. The noise will spread out to approximately two octaves and will have a peak level at the frequency of:

$$f_{max} = 200 \frac{V_b}{d \cos \alpha} \quad (1.1)$$

Where V_b is the velocity of the fan blade [m/sec], d is the maximum thickness of the blade [mm] and α is the angle of the blade in degrees. By changing these parameters, one may shift the frequency of the noise to less annoying regions.

The fan blade angle α influences the location of the boundary layer and thus amount of wake. This is depicted in the figure below.

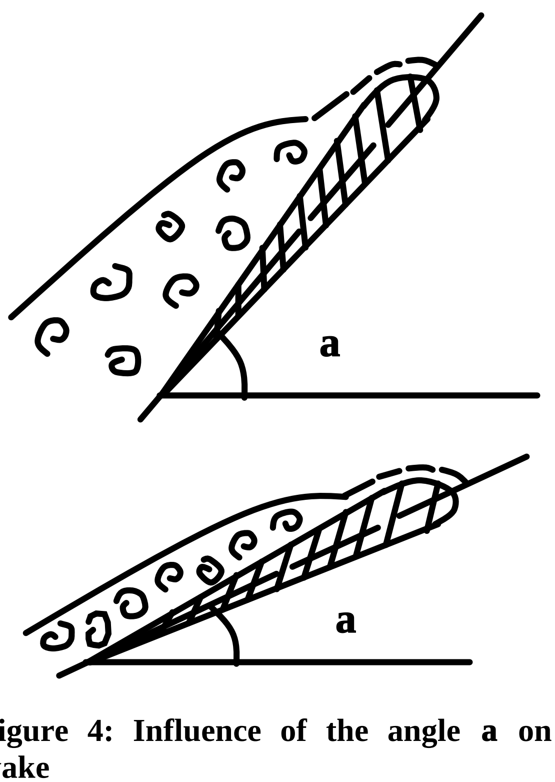

Figure 4: Influence of the angle a on wake

Wake results in noise (as discussed above) and will therefore have to be minimised. The aerodynamic efficiency is also dependent on α [6].

THE MATTER OF TURBULENCE

As discussed in the section above, fluctuating forces perpendicular to the fan blade will play the biggest role in noise production. In the section above, the inlet airflow was assumed to be laminar. Often in more practical applications of fans, objects in the inlet stream will cause the airflow to be turbulent (specially in cooling fans). The effects of this turbulence is easy to explain in general, but difficult to calculate in exact values. A general relation is often expressed as:

$$L_{wtur} \propto V_b \, d_{eddy} \quad (1.2)$$

Generally, turbulence produces a maximal amount of noise (L_{wtur} in dB) when the size of eddy is greater than the maximum thickness of the blade. In that case, only one eddy a time will collide with the blade and therefore will result in the maximum excitation. The actual size of the eddy (d_{eddy}) is difficult to determine as the behaviour of turbulence is chaotic. It is therefore more useful to give a few examples of installation and the influence on turbulence in where turbulence (and thus noise) is generated.

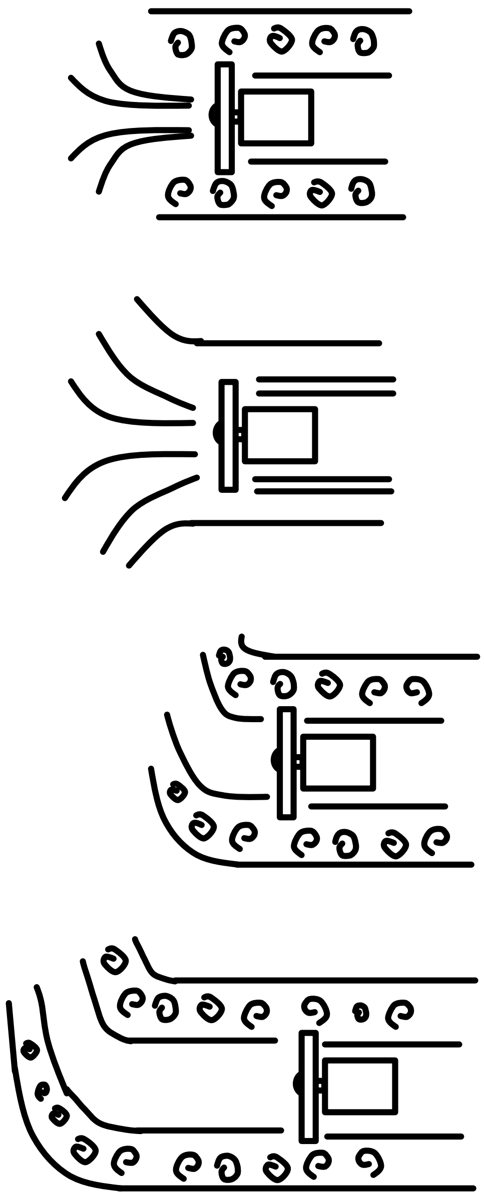

Figure 5: The influence of installation on flow turbulence

These figures point out the importance of roundings in the inlet and outlet of fan systems. If this is not possible, settling lengths will have to be introduced to quiet the flow.

The other parameter in relation 1.2 is the rotational velocity $\mathbf{V_b}$ of the fan blade. Decreasing $\mathbf{V_b}$ will have a linear effect on the reduction of noise. However, the working point of the fan will drop as well. Often, this is not allowed in design. In the diagram below, the effect of noise production of a fan at two speeds is depicted.

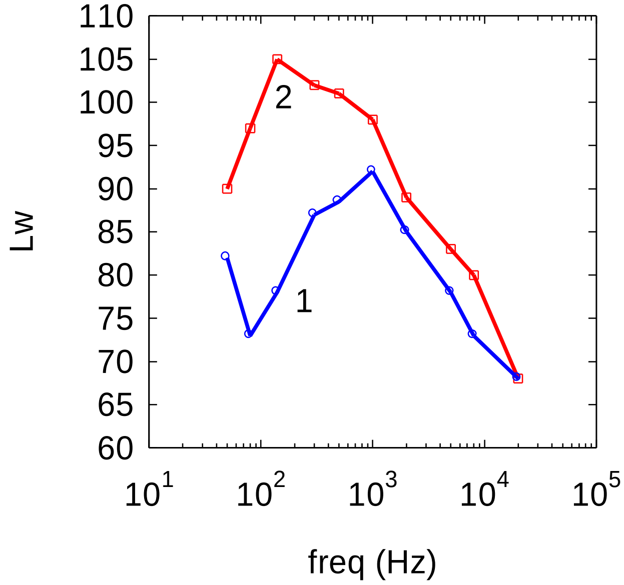

Figure 6: The effect of rotational speed on the production of noise
(1: f_v=9260 m^3/h, Dp=467 Pa
2: f_v=18730 m^3/h, Dp=284 Pa) [4]

OBSTRUCTION BY OBSTACLES

In many constructions of fan systems, it will not be possible to keep the inlet en outlet of a fan system totally smooth and rounded. Objects like motor support, gratings or steering vanes are often unavoidable in construction. These objects will disturb the flow and will therefore have effect on the noise production of a system.

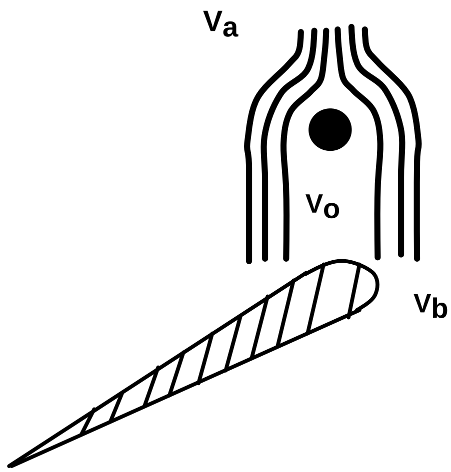

Figure 7: Obstacle at inlet of a fan.

The velocity of the airflow is lower just behind the obstacle. The difference in air velocity encountered by the fan blade will therefore result in fluctuating forces on the blade. These fluctuating forces are harmonic and will therefore produce short banded noise (a tone component). The frequency is easily adjusted by altering the number of obstacles, number of fan blades or fan blade speed (diameter or rotational velocity).

The effect of this source is even higher when the obstructing object is moving trough a medium as well. In this case aerodynamic collision will take place between the two flow fields, generating extra noise. Especially in multi-stage fan configurations, these effects will be dominantly present. Altering the (unequal) number of fan blades will shift the frequency of this noise.

Increasing the distance between the fan blade and the object of obstruction will introduce more settling length of the airflow. Noise can thus be reduced.

MULTI FAN SYSTEMS

There are two types of multi stage fan systems. Ones where fans are placed *parallel* and ones where fans are placed *serial* (multi-staging). Especially in multi-stage configuration, extra noise is introduced. As in the case of obstruction, the source of this noise is the disturbed airflow in the system. By means of efficiency, axial fans should be driven in opposite directions. In the following figures, different configurations of in multi-staging are shown.

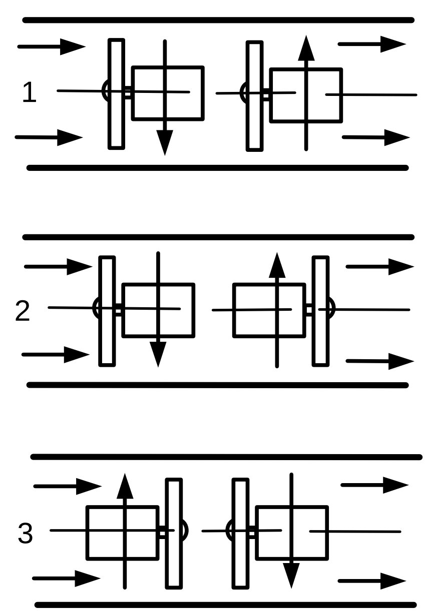

Figure 8: Different configurations of the multi-stage system

The extra noise introduced with these configurations is summarised in the table below.

Configuration	Extra noise [dB]
1	6
2	4
3	10

Table 1: Extra noise added in different configurations [1]

This points out that configuration 2 is most quiet. However, efficiency will drop with increasing the distance between the fan-blades. Therefore the configuration 1 is most often used in serial systems, ignoring the effects of noise production.

Another solution is to place the fans parallel. In this case, the heavy effects of obstruction will stay out (figure 9).

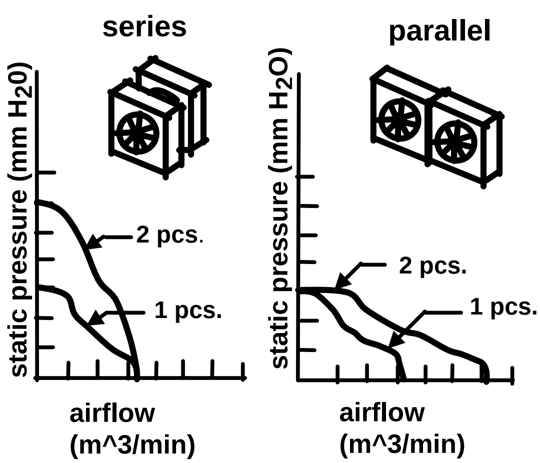

Figure 9: Showing the effect of parallel fan configuration [9]

The biggest problem in this parallel configuration is that the energy of the fan is mostly converted to kinetic energy instead of static pressure. Kinetic energy will be lost with the very first collision of the medium [7]. Kinetic energy is therefore less energy efficient.

CONCLUSIONS

Most general noise can be reduced when striving for design with maximum aerodynamic efficiency. In other words, one should try to reduce the amount of turbulence in the medium. Turbulence can be reduced choosing the right geometrical roundings, avoiding obstacles and keeping the inlet and outlet of the system clear. Some examples of turbulence poor design were given.

The most important parameters which will effect the fan's noise production are: blade angle, blade velocity, number of blades, amount of obstacles, geometry and distance of obstacles and the state of the inlet and outlet airflow.

Knowing these parameters, one could come to the right choice of a fan and improve the systems acoustic performance. In the design stage, one will have a general idea in the mechanisms that play part in the systems noise production.

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