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[N477] New experimental techniques to evaluate fan aerodynamic noise

First Author: Francesco Asdrubali

*Affiliation: University of Perugia
Department of Industrial Engineering
Via G. Duranti 67, 06125 Perugia, Italy
Email address: fasdruba@unipg.it*

Second Author: Giulio Pispola

Affiliation: University of Perugia

ABSTRACT

To foresee and then minimize the noise due to a ventilation circuit, it is necessary to deeply analyse each of its elements. Fans are the main noise sources of these systems.

The aim of the work was to find the fan acoustic fingerprint of a typical medium size centrifugal fan, for industrial and civil uses; though a fan could look like a rather simple and standardized machine, it is known that its acoustic performance is the result of various, different phenomena.

Thanks to intensity measurements, according to ISO 9614-1, and intensity maps, the different sources of the fan and their relative importance were identified and, in particular, inlet, scroll and outlet.

Pressure measurements were performed in a semi-anechoic chamber, according to ISO 3745, focusing on aerodynamic noise. Discrete tonal components in the overall power spectrum appeared indeed to be limited, with respect to the broadband noise, thanks to the scroll cut-off optimisation.

The results also confirmed that aerodynamic noise is essentially dipole noise, associated to turbulent boundary layer scattering at the blade trailing edge; evidence was found that overall power level depends on N^6 .

Several fan noise studies demonstrate that broadband noise attenuation needs a careful blade design and minimum turbulence at the inlet, but a deeper view inside the signal can reveal hidden characteristics. In this way, apart from frequency analysis, time domain analysis and Wavelet transform were used. The latter, in particular, stressed the self-similarities of the signal, consequence of its chaotic nature.

INTRODUCTION

Fans are noisy machines. Their use is so widespread that there is a significant interest in reducing their acoustical emissions. In particular, when dealing with ventilation and air-conditioning systems, one should consider that sound power of a fan could be transmitted along the circuit and spread along a building [1].

Classical engineering approaches consist of silencer at the fan outlet or along the ducts, but these have some limits: for example, silencers increase pressure losses and they are effective in a limited frequency range. This paper presents the characterization of a commercial machine in order to look for actual noise sources: working directly on the source can avoid expensive reduction method *in situ*.

It is known that all the elementary acoustical sources contribute to generate fan noise: monopoles, dipoles, and quadrupoles. However, in medium sized machines, as the one we focused on, there is experimental evidence that the main sources are dipolar in nature. Such phenomena as non-stationary forces, due to turbulent flows acting on rigid surfaces, constitute the fundamental noise causes: these phenomena are typically chaotic and therefore not easy to evaluate, at least without numerical analysis or particular measurement methods of the fluid dynamic field inside the machine [1].

Moreover, fan noise is dependent on its point-of-rating and on installation effects: a typical centrifugal fan for industrial and civil applications in a free inlet-free outlet configuration was characterized, that is without any connected duct. This is necessary to avoid installation effects.

The machine chosen is a 42 forward-curved blades machine with an integrated single-phase asynchronous motor and double inlet (fig.1). Its design allows reduction of the tone at the blade passage frequency (BPF): indeed, since it was verified that the main spectral components are broadband in nature, attention was focused on their origin.

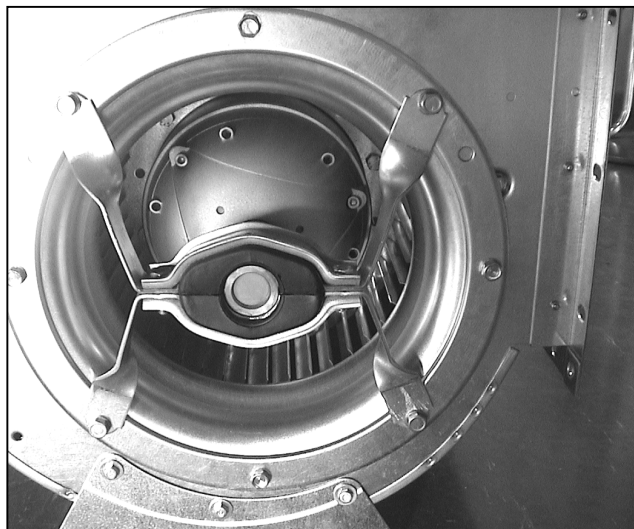


Fig.1: centrifugal fan used for measurements

INTENSITY MEASUREMENTS

Intensity measurements were carried out with Brüel & Kjær Type 3548 sound intensity probe; calculations were performed by means of B&K Noise Source Location software.

According to standard ISO 9614 part 1 [2], normal sound intensity was measured on a 104 points parallelepiped grid surrounding the source (fig.2). Due to the high flow rate (more than 6000 m³/h, with the fan connected to the electrical network), results were overestimated in the low frequency range ($f < 160$ Hz), since wind induced noise was acting on the probe in the front side of the grid, corresponding to the fan outlet [3].

Anyway, intensity maps (fig.3) and narrow band power spectrum (fig. 4) supply interesting information. In the medium and high frequency range, only the blade passage frequency tone is evident (at the 770 Hz in this case). Broadband noise has various causes: among them, turbulence at the inlets and in the boundary layers. The former mainly shows its effects for $f < 1000$ Hz, where spectrum is more jagged. At higher frequencies, the latter produces a smoother, substantially flat spectrum.

The maps put in evidence that outlet, inlet and casing have to be considered as different sources. Higher intensity levels are relative to the inlets with respect to the casing, but their relative importance is almost equal, as one can appreciate from emitted power level estimate.

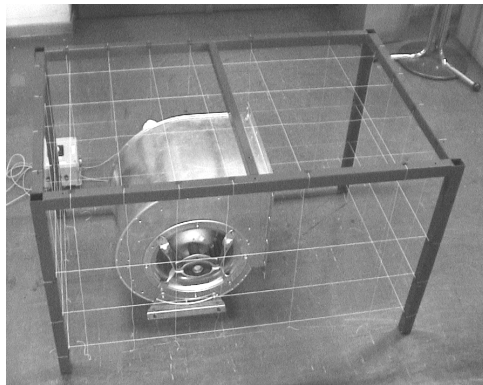


Fig.2: sound intensity measurements: grid surrounding the source.

Intensity Mag.
Freq: 160-1.25kHz

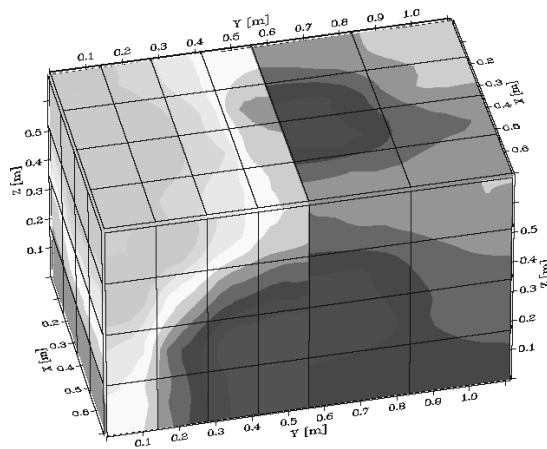
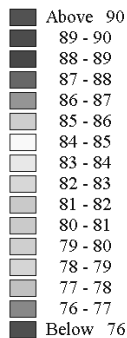


Fig. 3: sound intensity measurements: example of intensity map in the low frequency range.

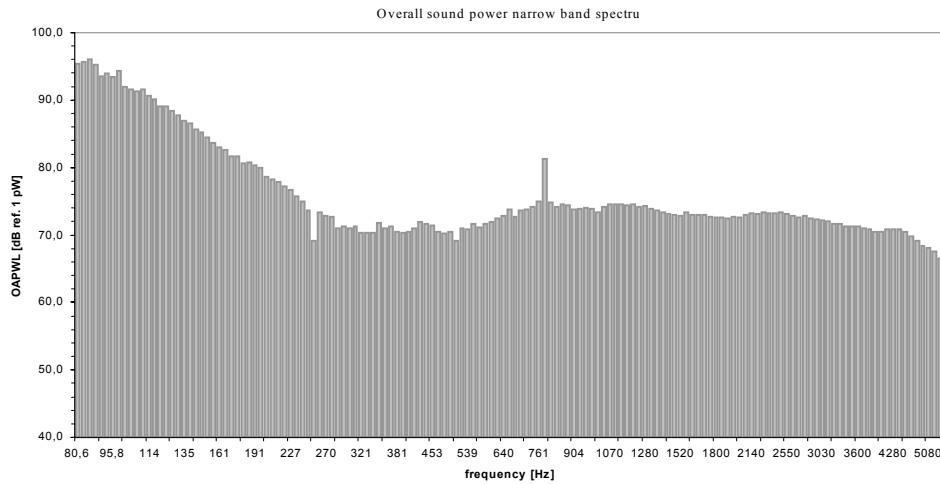


Fig. 4: overall sound power spectrum in 1/24-octave bands. In the low frequency range, wind-induced noise is evident.

PRESSURE MEASUREMENTS

Sound pressure measurements were performed in a semi-anechoic chamber (placed at the VUB of Brussels) by means of a standard ½” condenser microphone. According to the ISO 3745 [4], measurements were performed on 10 points (specified by the standard) on a hemispherical surface surrounding the source (fig. 5). The relative position of the points and of the fan outlet avoided direct impact of the airflow on the probe.

Constant bandwidth pressure spectra in the various points (fig. 7) have been evaluated together with power spectra at five different rotational speeds, controlled via voltage variation (fig. 6).

Power spectra are quite similar in the medium, high frequency range; this suggests that the main causes, as trailing edge scattering of the turbulent boundary layer, are speed-independent.

Discrete spectral components are concentrated below 1000 Hz: one is occurring at the BPF, others at harmonics of the network frequency (50 Hz) and other probably related to the inlet turbulence and to resonance effects of the casing structure.

At the same time, it is evident that the most relevant part of the spectrum is broadband noise.

From these results, it was verified that the overall sound power depends on the sixth power of the rotational speed:

$$P \propto N^6 \quad (1)$$

This is consistent with the law derived from dimensional analysis of the sound field produced by a small rigid surface, interfering with a turbulent flow [5], here written as mean square fluctuating density:

$$\overline{\rho'^2} \propto \rho_0^2 \left(\frac{l}{r}\right)^2 M^6 \quad (2)$$

Such a result indirectly confirms the dipolar nature of the most significant noise sources (fig. 8).

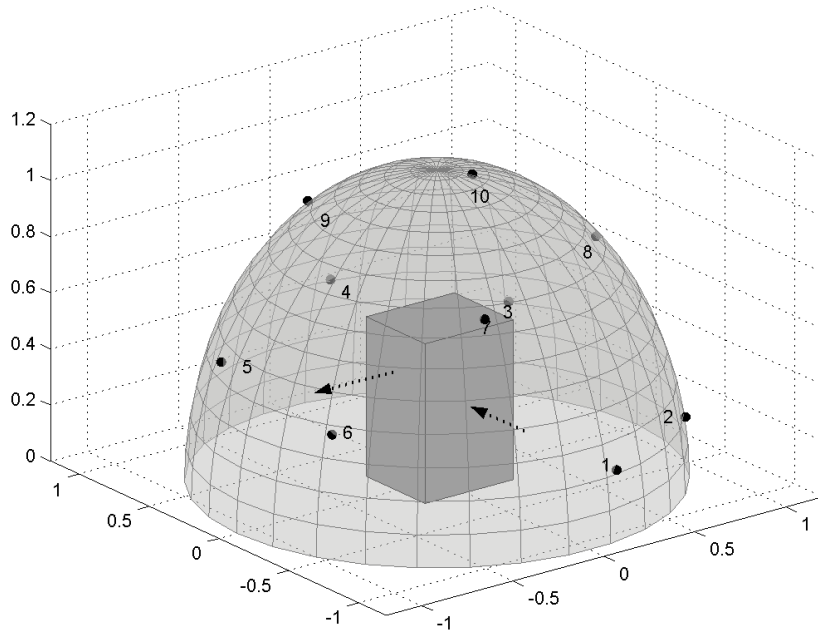
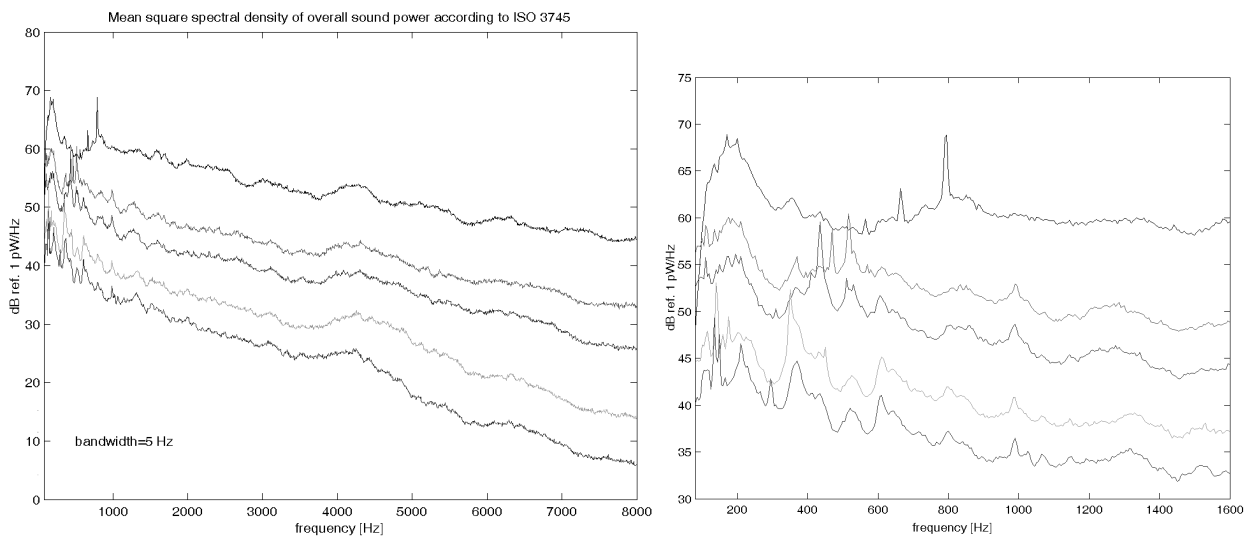


Fig. 5: pressure measurements: hemispherical surface (radius = 1.1 m) used for measurements in the semi-anechoic chamber. Arrows schematically indicate airflow directions at the inlet and outlet. Microphone positions are specified.



a) b)
Fig. 6: pressure measurements: narrow band sound power mean square spectral densities at five different rotational speeds. a) complete spectrum, b) detail at the low and medium frequencies. Bandwidth: 5 Hz.

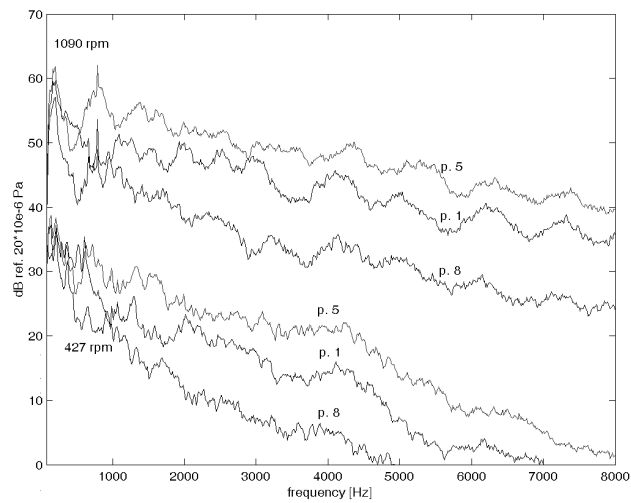


Fig. 7: pressure measurements: mean square spectral densities of sound pressure for three different points and two different speeds. Bandwidth=10 Hz.

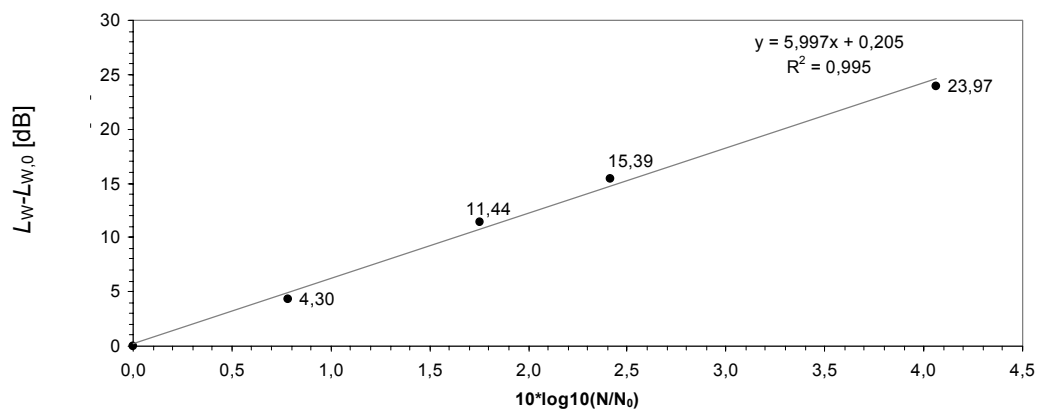


Fig. 8: pressure measurements: overall sound power dependence on rotational speed. Experimental data and linear regression. At the top, equation and correlation coefficient for the regression.

SIGNAL ANALYSIS

Frequency analysis is not enough to look deeply inside the noise generating phenomena. Indeed, time information is lost because of Fourier transform [6].

The pressure signals recorded in the semi-anechoic chamber were analysed by means of classical and innovative techniques, such as correlation functions and Wavelet transform.

The former stresses on the difference between the sources: signals recorded in front of the scroll have typical chaotic behaviour, whereas signals recorded at the outlet have a quasi-periodic behaviour that suggests an intrinsic instationarity. It is possible to distinguish around 18 periods in one second of autocorrelation function; the motor rotational frequency was about 18 Hz during these measures (fig. 9).

Wavelet transform looks inside the signals in time-scale domain. Non-stationarity is still evident and self-similarities appear at different scales. This could probably be consequence of the chaotic nature of noise generation, which should reveal itself with fractal or pseudo-fractal behaviour (fig. 10).

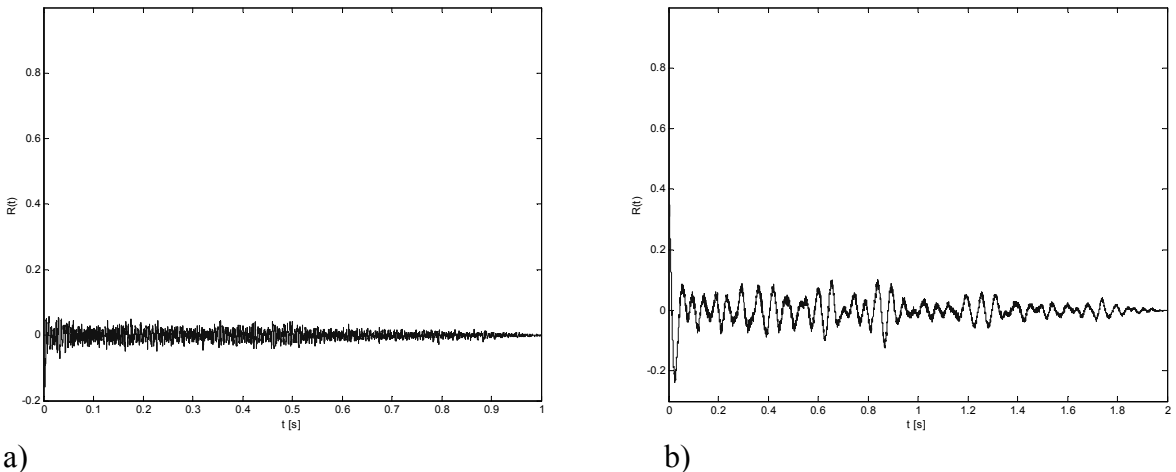


Fig. 9: autocorrelation functions, normalized at one, evaluated from two pressure signals ($f_s = 48000$ Hz). a) Point 1, b) Point 5 of the hemispherical surface.

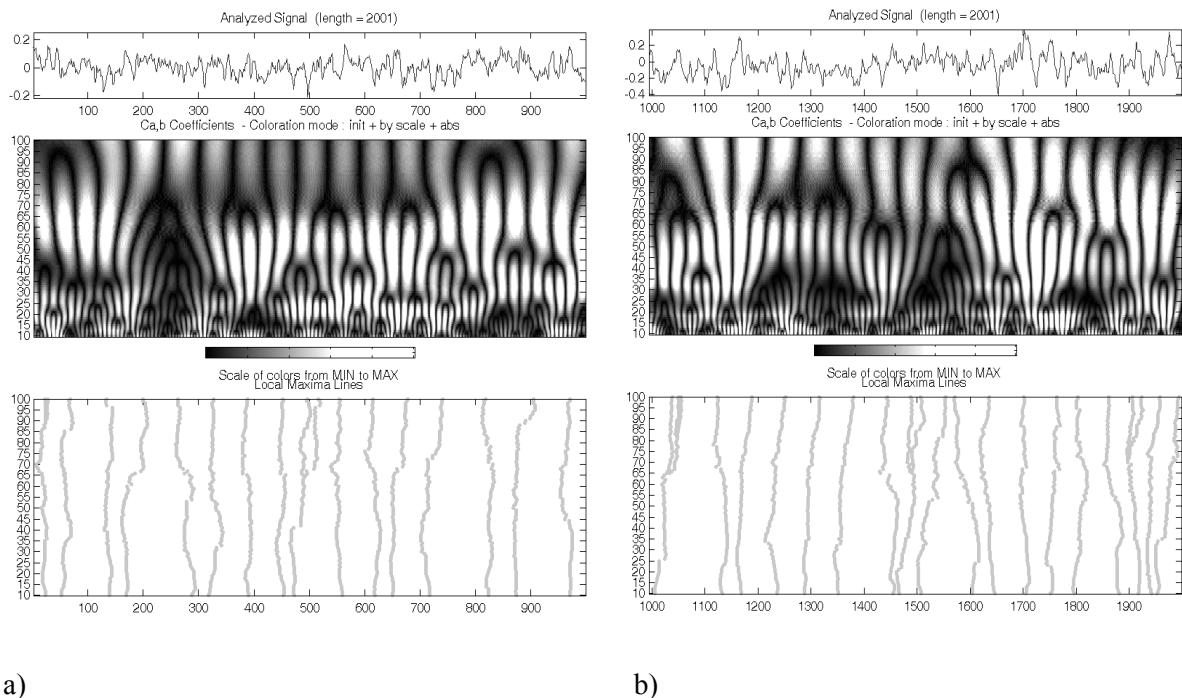


Fig. 10: Continuous Wavelet Transform coefficients evaluated with the wavelet Morlet for 1000 samples ($f_s=48000$ Hz) of two pressure signals. a) Point 1, b) Point 5 of the hemispherical surface.

CONCLUSIONS

Effective methods of noise reduction are currently used in design stage of fans. However, they are mainly intended to reduce discrete spectral components. This research has suggested that designers should focus their attention on non-stationary forces acting on rigid surfaces and that, before looking for design solutions to reduce aerodynamic noise, is fundamental to correctly understand its causes.

Intensity maps and pressure spectra put in evidence the differences between inlet, outlet and casing, that should be regarded as separated noise sources.

There are various, co-existing phenomena and their analysis just by means of power spectra is not sufficient. Alternative instruments can be useful. However, a deeper investigation is necessary to properly explain results in the time domain, in particular to find out the real nature of the signals. This could help in identifying the fundamental sources and in foreseeing the noise generated by such machines. Nevertheless, it should be taken in mind that such phenomena are essentially chaotic in nature and therefore theoretically unpredictable.

ACKNOWLEDGEMENTS

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LIST OF SYMBOLS

- f = frequency [Hz];
- f_s = sampling frequency [Hz];
- l = linear dimensions of the source [m];
- M = airflow Mach number;
- N = impeller rotational speed [rpm];
- L_W = sound power level [dB referred to 1 pW];
- r = observer-source distance [m];
- R = autocorrelation function;
- t = time;
- P = sound power [W];
- ρ' = fluctuating (acoustical) density [kg/m^3];

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