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Quantification of structure born sound using scanning laser velocimetry and BEM radiation calculations

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Abstract

Fans are important noise sources in electronic systems. These devices are typically noisier when they are installed in systems. A standardized test methodology is available to experimentally determine the effect of the backpressure on the fan acoustic emission. In addition, the source character changes when it is installed because of the coupling with acoustic cavity modes. Finally, there is structural coupling between the fan and the installation structure. This paper outlines a new technique to quantify the contribution from the structure born sound by using scanning laser Doppler Velocimetry and a consequent boundary element calculation of the radiated sound. A fan is mounted to a square plate for this purpose, and acoustic and vibration measurements are performed. By using the new technique the contribution of the structure-born sound is quantified.

Resumen

Entre las principales fuentes de ruido en computadoras personales se encuentran los ventiladores que forman parte de los sistemas de enfriamiento. La generación de ruido de los ventiladores aumenta cuando estos se encuentran instalados en una carcasa. Existe actualmente un metodología establecida en normas internacionales para determinar experimentalmente el efecto de la contra presión en la emisión sonora de los ventiladores. Un fenómeno adicional que puede contribuir a este aumento en la generación de ruido es el cambio en el carácter de la fuente que puede ocurrir debido al acoplamiento con los modos de la cavidad. Por último, existe acoplamiento estructural entre el ventilador y la carcasa. En el presente trabajo se describe una metodología para cuantificar la contribución de la radiación sonora generada en la estructura a través de una técnica experimental usando velocimetría láser seguida del cálculo numérico de la radiación sonora mediante el método de elementos de frontera. Para ilustrar la metodología propuesta, se montó un ventilador en una placa y se llevaron a cabo mediciones de ruido y vibraciones para cuantificar la radiación sonora generada en la estructura.

1 Introduction

Low acoustic noise emissions from personal computers is important in order to comply with emerging eco-labels and government procurement specifications, and to meet customer demand for quieter systems. The fans that are present in these systems to provide airflow for cooling are primary noise sources. It is well known that the noise emission of fans under installed conditions is different from the acoustic emission of the fan. A specific ISO standard was developed to quantify the effect of the backpressure on the acoustic noise emission, using a fan plenum test device¹. In addition, panels and obstructions can change the behaviour of acoustic sources such as fans, leading to significant increases in the radiated sound power in some cases². The source character of the fan noise changes when the fan is installed. The reason for the change is because of the coupling with acoustic cavity modes^{3, 4, 5}. Finally, the transmission of vibrations to the chassis through the mounting structures and the consequent radiation of sound from the panels is a key factor that needs to be quantified⁶.

In a previous study⁴, an experimental setup was developed to quantify the change in source character when a fan is mounted on a plate. The acoustic emission of the fan was measured when it was unconfined and when it was mounted on a plate, where the plates varied in size. The amplification of the noise emission was found to increase with plate size, see Figure 1. The dipole character of the fan noise is broken up by the plate, resulting in increased acoustic noise. Experiments were performed for different mounting conditions: hard mount, soft mount and decoupled. In the decoupled case, the fan is located close to, but not actually making physical contact with the plate. In general, the results correspond well to the results of a boundary element model of a dipole in the presence of a solid, rigid surface.

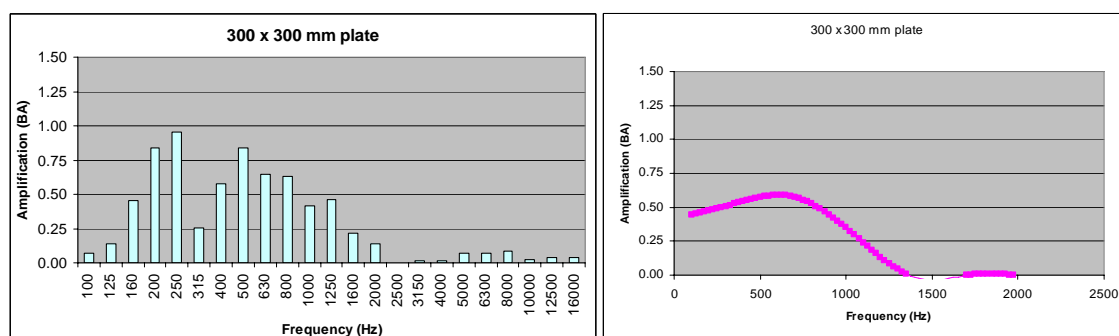


Figure 1. Measured and simulated amplification for fan with plate⁴.

The current paper extends this previous work and outlines a new technique to quantify the contribution from the structure born sound by using scanning Laser Doppler Velocimetry (LDV) and a consequent boundary element calculation of the radiated sound.

2 Problem Statement

The goal of this study is to develop a methodology to separate airborne and structure borne sound contributions. An axial fan was mounted to a plate and acoustic and vibration measurements were performed. The vibrations were captured through the velocity distribution on the surface of the plate, and the measurements were performed using a scanning laser Doppler system. The contribution of the structure born sound was quantified using a boundary element model, using the measured velocity profile on the plate as boundary conditions for the radiation calculation.

3 Experimental approach

In this section an overview of the experimental approach for obtaining the vibrations is described, as well as the sound power setup for obtaining the overall sound power. The vibrations obtained from the Polytec Laser Doppler Vibrometer⁷ are then exported to LMS Virtual Lab⁸ software, where the component of acoustic noise radiated by the vibrating plate is calculated.

3.1 Experimental setup

The experimental setup consists of mounting a standard 92 mm axial fan on a metal plate using four bolts, one in each corner (hard mount). The fan is a seven blade fan with three struts. The plates used in this investigation are three square steel plates with the outer dimensions of 150 x 150 mm, 200 x 200 mm and 300 x 300 mm. All the plates are 0.8 mm thick. There is an opening in the middle of the plate to allow for airflow. Pictures are shown in Figure 2 and Figure 3.



Figure 2. Steel plates and 92 mm fan configurations.

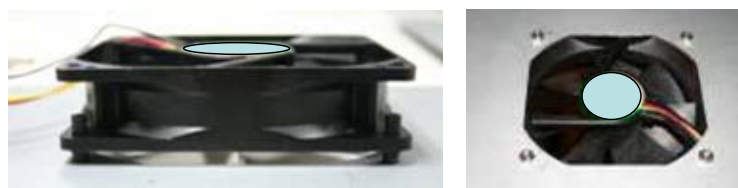


Figure 3. Details of fan mounting and airflow opening.

3.2 Scanning laser Doppler velocimetry

The measurements are performed using a Polytec PSV 3000 system. The plate is suspended in the middle of a precision grade anechoic chamber (according to ISO 3745), as shown in Figure 4. The chamber is mounted on dampers which mechanically isolate it from building vibrations.

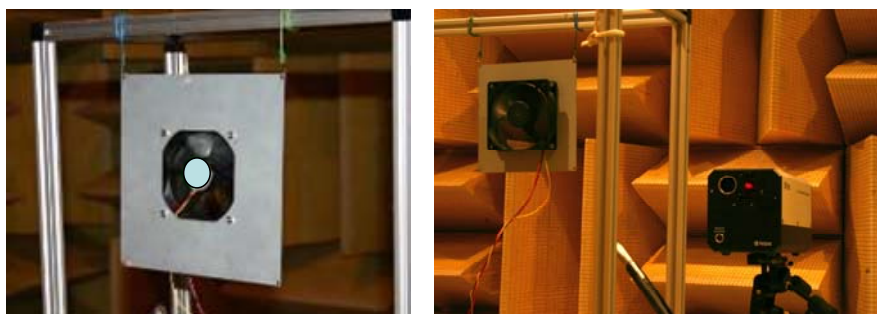


Figure 4. Plate configuration and scanning Laser Doppler Vibrometer setup

For the measurements, a 40 x 40 grid is used for all plates. The scanning distance is 97 cm from the scanning head to the steel plate. The fan speed is held at a mean value with +/- 10 RPM approximately throughout the entire scan by applying a constant voltage. The key to the vibration measurements is the use of a reference microphone signal. This allows capturing the vibration magnitude and also the phase information. This is crucial in the consequent prediction of the acoustic radiation. The reference microphone is a Bruel & Kjaer 4190 condenser microphone, and is calibrated before each set of experiments. An example of typical vibration data is shown in Figure 5 for one experimental run. In this specific experiment, the fan was rotating at a speed of 1500 RPM and was mounted on the 200 x 200 mm plate. The map in Figure 5 shows the vibration velocity magnitude at a specific frequency, in this case 301.6 Hz.

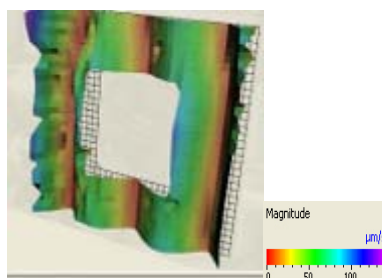


Figure 5. Typical vibration data for the 200 x 200 mm steel plate.

3.3 Sound power determination

The radiated sound power was measured in a hemi-anechoic chamber, following the guidelines provided in ISO 3745⁹. A microphone array was used with 10 Bruel & Kjaer 4190 microphones. Each of the microphones was calibrated before each series of experiments. The emitted sound power was measured for the fan in free space, the fan hard mounted to the plate, soft mounted to the plate and decoupled from the plate.

4 Numerical simulations

The velocity distributions for the measurements were imposed as boundary conditions in a boundary element calculation. This section outlines the transfer and acoustic radiation predictions.

4.1 Data transfer from scanning laser Doppler Velocimetry

An automated transfer of the data from the Polytec scanning laser system to the LMS Virtual Lab program was developed. The universal file export option using the SDR format is used for this purpose. The measurement distance between the scan head and the plate has to be specified during the export in the Polytec system. Not all the measured vibration data is exported, since this leads to excessive file size. The main interest is in the high amplitude vibrations, so the frequency bands of interest (that don't necessarily correspond to the plate natural frequencies) are selected and only this band of data is exported. These high amplitudes that result are a combination of the excitation spectrum and the modal behaviour of the plate. The measured data appears as a mode set in Virtual Lab, and is used as a boundary condition set. Along with the measured velocities, the mesh and elements are imported. Caution has to be taken when transferring data. Points that have an overload or invalid designation in the

Polytec system are not included in the export. In the Polytec software however, these points might still be visible in plots because they are interpolated, depending on the visualization settings.

4.2 Boundary element calculation

As outlined before, the mesh and velocity distributions are imported using the universal file format. Consequently, a boundary element calculation is carried out using an indirect uncoupled approach. A spherical field point mesh with a radius of 2 m and 866 points is used to calculate the radiated sound power. The radiated sound power is only calculated at the frequencies corresponding to the frequencies of the bands in the mode set as shown in Figure 6.

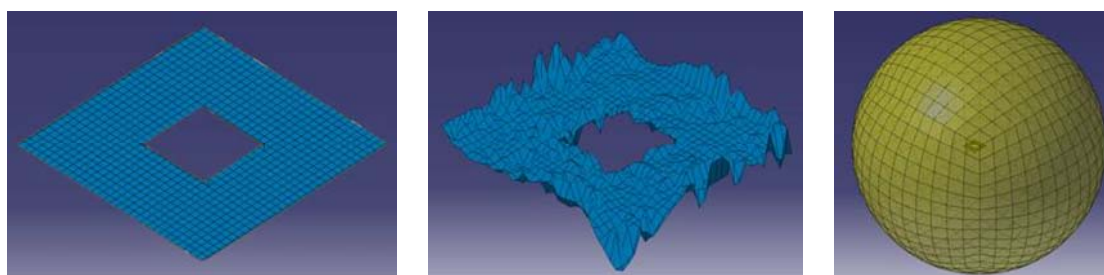


Figure 6. Structural mesh, example plate deformation and field point mesh.

5 Results and discussion

In this section, the results of the experiments and simulations are outlined. First, the experimental results of the sound power measurements are shown, followed by an overview of typical measured velocity distributions. Finally, the radiated sound from these vibrations is presented and compared to the overall measured values.

5.1 Sound power measurements

The results of the sound power measurements are given in Figure 7, 8 and 9.⁴ The results shown are for four different fan installation conditions where fan, refers to the measured fan sound power without any mounting condition. Hardmount refers to the fan bolted tightly to the plate. When special rubber connectors are used to hold the fan close to the plate and at the same time provide some damping between the fan and the plate is referred to as softmount. Finally, the decoupled legend refers to the case when the fan is held very close to the plate without making physical contact, therefore avoiding direct transmission of mechanical vibrations from the fan to the plate. BG refers to the back ground noise measured inside the anechoic chamber before each set of experiments.

The results indicate that the acoustic emission increases as the fan is hard mounted to the plate. This amplification is mainly of a low frequency nature and increases with plate size. In general, the differences between the hard mount, soft mount and decoupled cases are small, suggesting that the influence of vibration contributions is small. There is however some distinct peaks in the hard mount case. The spectrum of the noise is mainly of a broadband character with distinct peaks at the blade pass frequency and its higher harmonics. It is also clear that at lower RPM amplification is low for all mounting conditions.

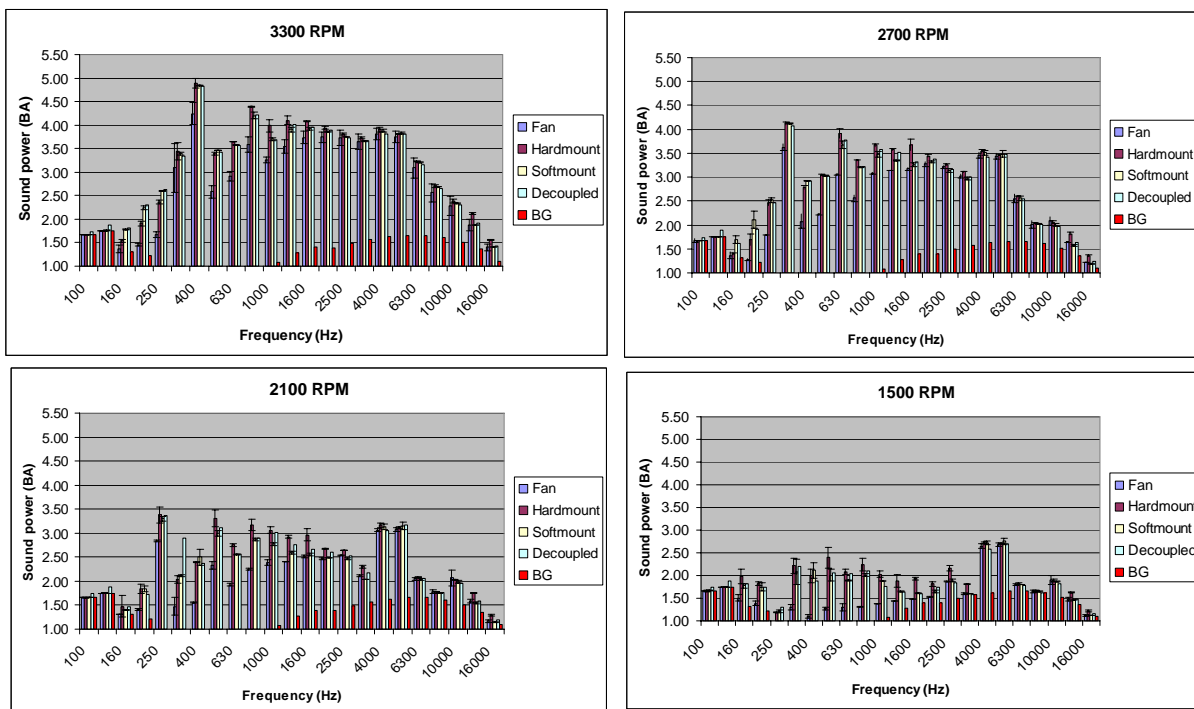


Figure 7. Sound power measurements for fan on 300 x 300 mm plate.

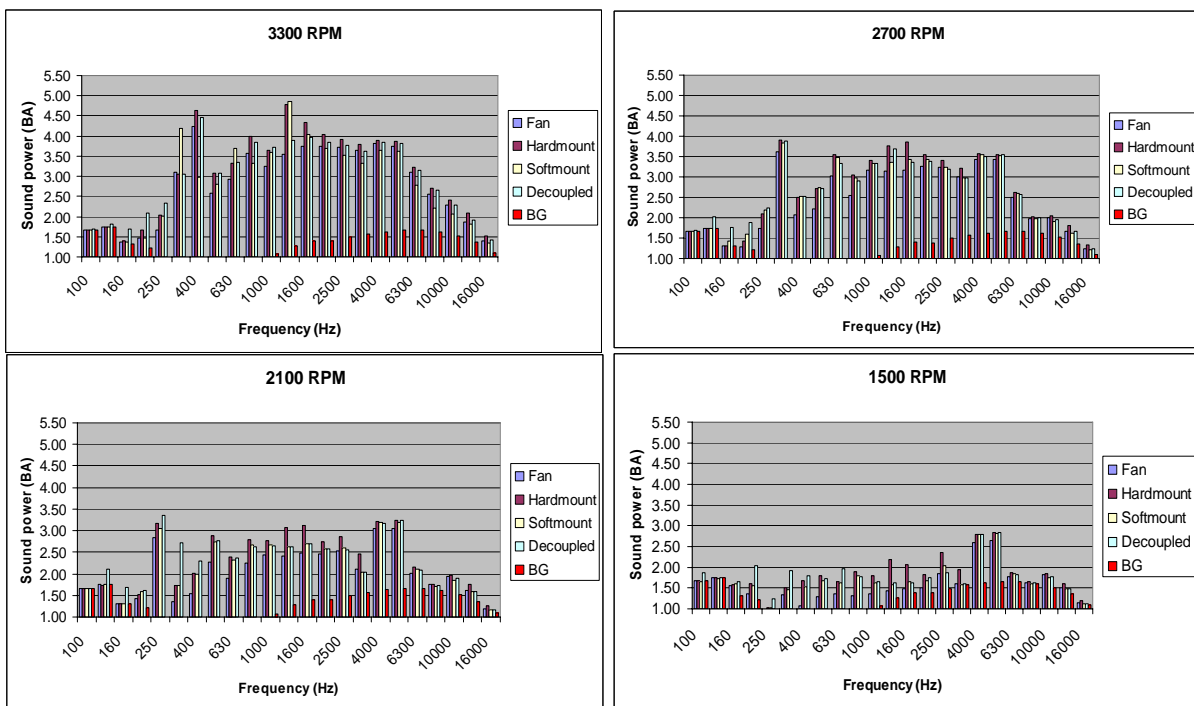


Figure 8. Sound power measurements for fan on 200 x 200 mm plate.

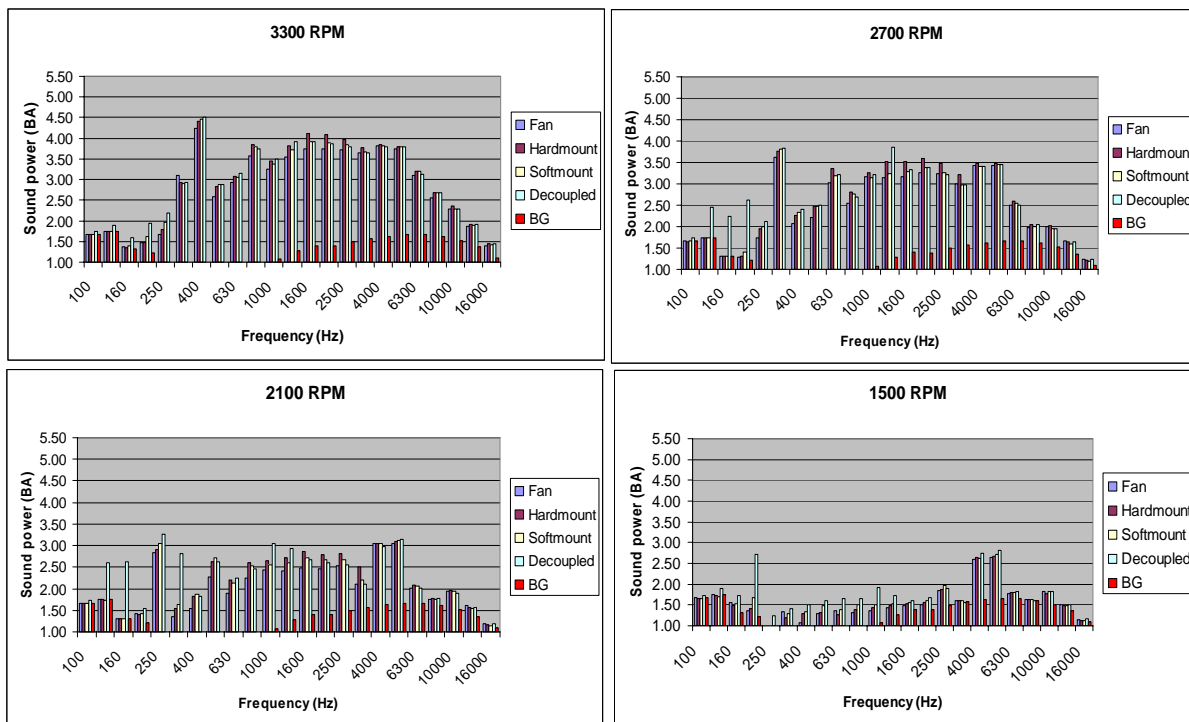


Figure 9. Sound power measurements for fan on 150 x 150 mm plate.

5.2 Representative velocity maps

A set of representative velocity fields are shown in Figure 10. Note that the scales for these plots are different. Typical velocities are approximately between 50 $\mu\text{m/s}$ and 500 $\mu\text{m/s}$.

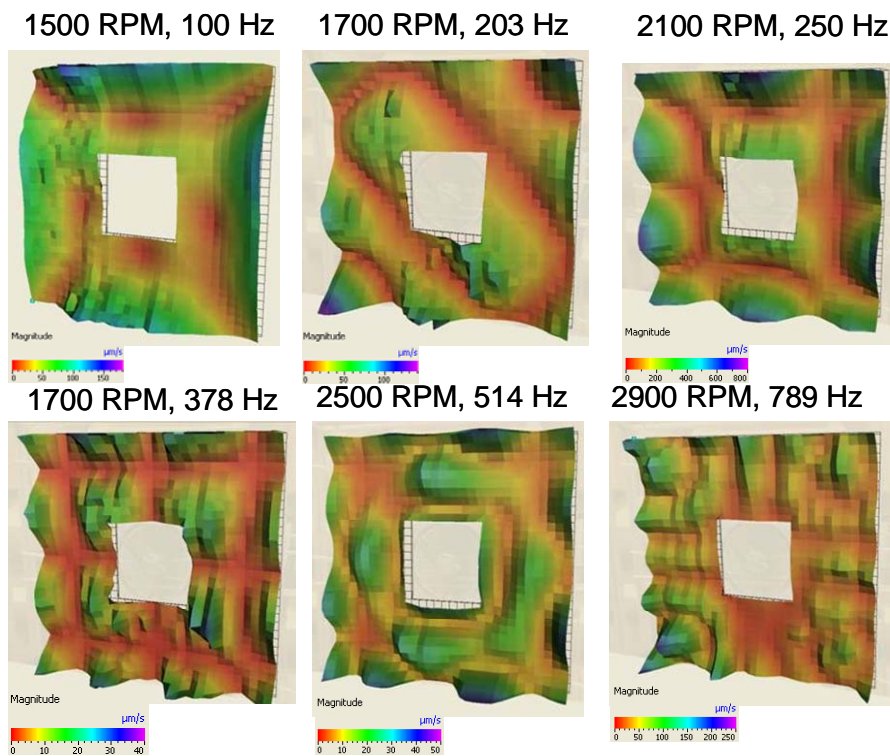


Figure 10. Representative velocity maps for the 300 x 300 mm plate.

The velocity maps illustrate the modal behaviour of the plate at low frequencies. The vibration shapes increase in complexity as frequency increases, and at frequencies around 1.5 kHz there are no longer a sufficient number of grid points to accurately capture the vibration shape. For this reason the acoustic radiation predictions will only be carried out for the low frequency range. Typically, the vibration excitation for a fan source shows peaks at the fundamental rotation frequency and its higher harmonics. Therefore it can be expected that the vibration magnitude of the plate is high when one of these excitation frequencies coincides with a resonance frequency of the plate.

5.3 Structurally radiated sound

The radiated sound from structural vibrations as a function of frequency are shown in Figures 11, 12 and 13. The figures indicate that the structurally induced noise is lower than that of the pure fan noise. Even though the amplitudes of some of the low frequency vibrations are higher, the radiated sound is relatively low because of the low frequency and because of the additional A-weighting that was applied. In general, the radiated sound power is slightly higher for the larger plate sizes, although some exceptions exist because of the modal coupling that occurs at specific frequencies and fan speeds. For example, between 2700 and 2900 RPM there are some significant contributions that were also observed in the sound power experiments.

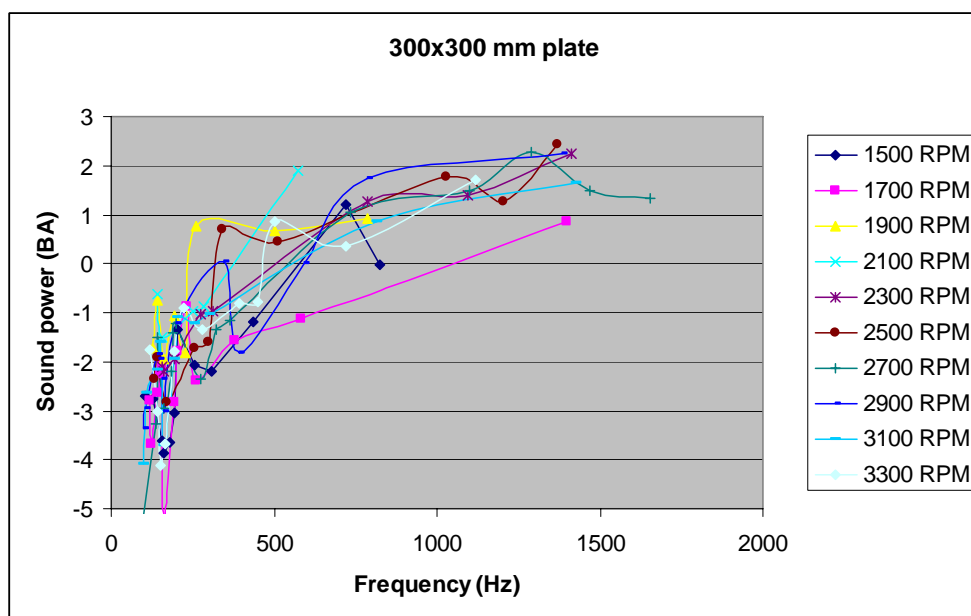


Figure 11. Radiated sound power for 300x300 mm plate.

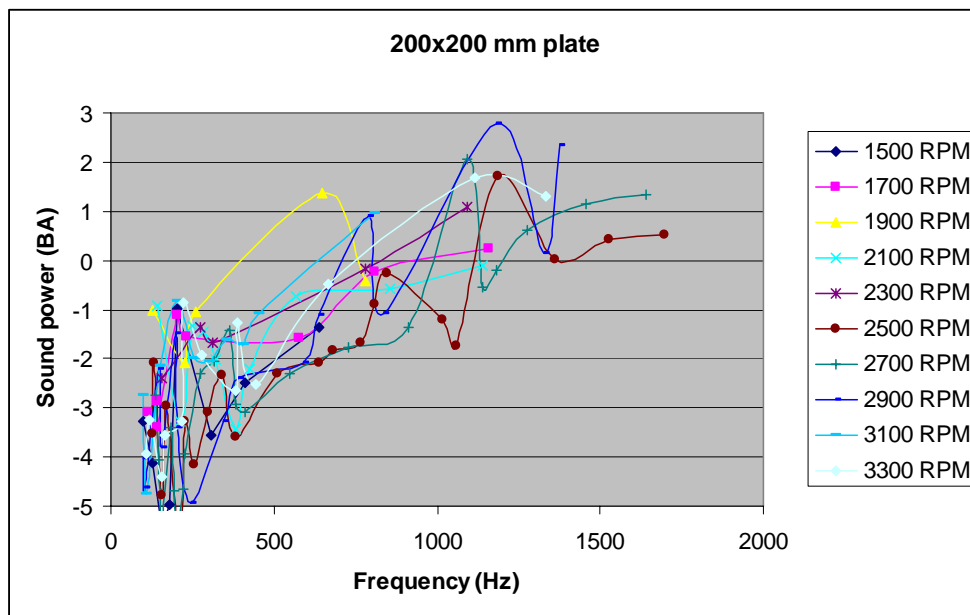


Figure 12. Radiated sound power for 200x200 mm plate.

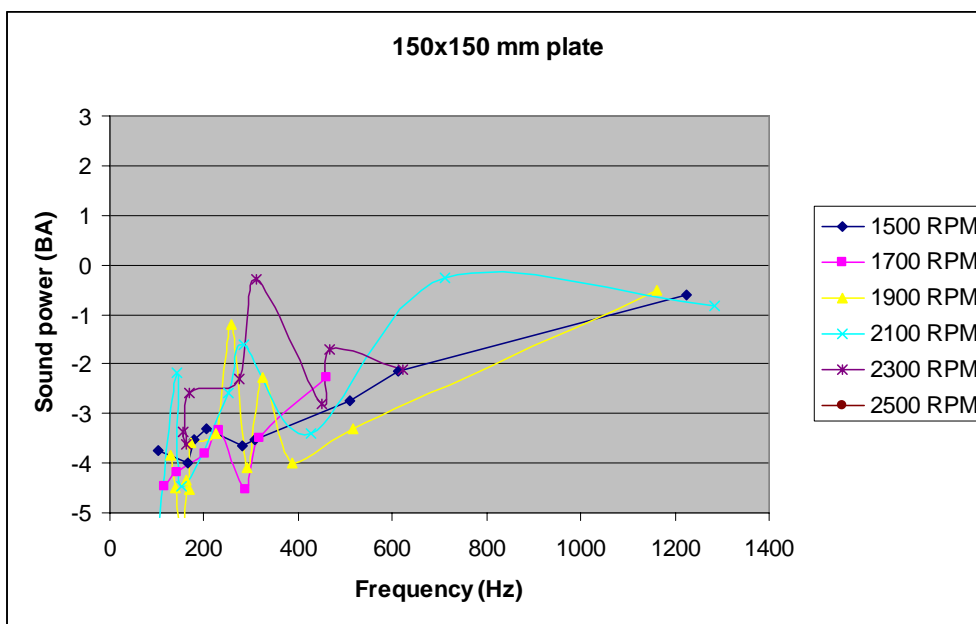


Figure 13. Radiated sound power for 150x150 mm plate.

The radiated sound power does not show a clear trend with fan speed, as opposed to the aero-acoustic fan noise. The radiated sound power from a fan source typically has a logarithmic dependence on the fan speed. The radiated sound from the structural vibrations, integrated over the frequency band up to 1.5 kHz, is given in Figure 14. There are peaks as a function of the fan speed, corresponding to modal coupling between the fan excitation and the plate response.

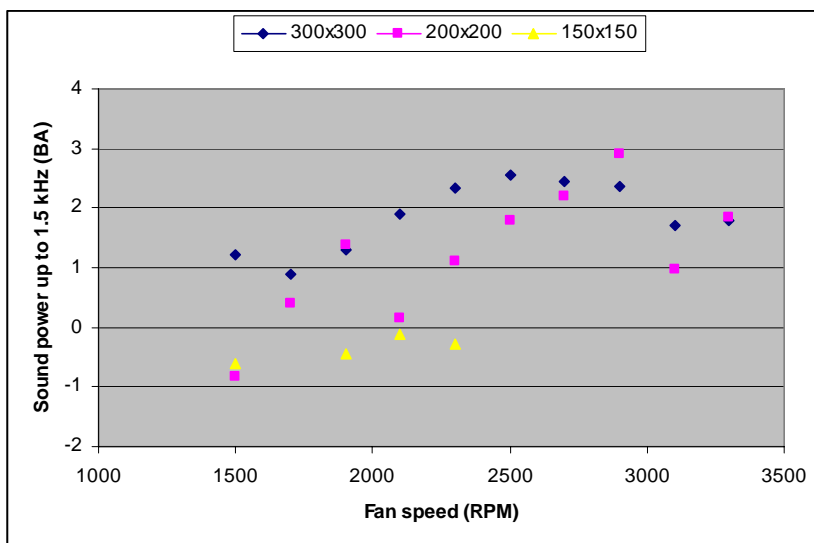


Figure 14. Radiated sound power as a function of fan speed.

6 Conclusions

A methodology has been developed to quantify the contributions of the radiated sound from structural vibrations. Detailed surface velocity profiles are measured with a scanning Laser Doppler Vibrometer. The data is transferred to a numerical simulation package and the radiated sound power is calculated from the associated surface vibrations using a boundary element technique. In the case of an axial fan mounted on a plate, it is shown that the contribution of structurally radiated noise is very low compared to that of the airborne sound. Only in very specific cases is the structurally radiated sound of the same order of magnitude as the aero-acoustic fan noise. The structurally radiated sound is shown not to scale directly with the fan speed, as opposed to the aero-acoustic fan noise by itself.

Acknowledgements

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