Effect On Noise Emissions From Varying Distance Between Heat-Sink Fin To Cooling Fan Blade Tip

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ABSTRACT

The challenge to deliver performance improvements in computer graphic cards has surpassed the ability of finned, passive, cooling devices to dissipate the heat generated by next generation graphics processing units (GPU). The dissipation rates required by these latest GPU designs can only be delivered by more complicated thermal management systems which often require forced air cooling of finned heat sinks. The concurrent challenge to the industry is to provide this cooling while minimizing the noise generated by these cooling fans. One of the fundamental mechanisms for the generation of fan noise is the dynamic force fluctuations on the fan blade and how these fluctuations interact with fixed irregularities such as adjacent cooling fins. This study investigates the effect on the acoustic emissions resulting from the variation of the distance between the fan blade tips and the heat sink fins. A discussion and comparison of the measured results will be presented using both traditional analysis techniques as well as psychoacoustic or sound quality metrics. It was found that a minimum distance between the blade and adjacent obstructions is desired in order to minimize excessive noise levels. The minimization of the noise emissions also had a desirable effect on the sound quality analysis.

SOMMAIRE

Le défi de constamment améliorer la performance des cartes vidéo ont surpassé la capacité d'appareils de refroidissement passif consistant d'ailerons pour disperser la chaleur produite par les processeurs graphiques (GPU) courantes. La dissipation exigée par ces GPU modernes peut être livré seulement par les systèmes de gestion thermiques plus compliqués qui exige souvent l'utilisation du refroidissement à air forcé de passer des ailerons. Le défi simultané qui presse l'industrie c'est de fournir ce refroidissement en minimisant le bruit produit par les ventilateurs utilisés. Un des mécanismes fondamentaux pour la génération de bruit de ventilateur est la variation de forces dynamiques sur la lame du ventilateur et comment ces variations interactent avec les irrégularités fixes telles que des ailerons adjacents. Cette étude examine l'effet sur les émissions acoustiques qui résultent de la variation de la distance entre les pointes des lames du ventilateur et les ailerons de dissipateur thermique. Une discussion et une comparaison des résultats mesurés seront présentées utilisant les techniques d'analyse traditionnelles de même que des métrques psychoacoustique, ou de qualité du son. Il a été trouvé qu'une distance minimum entre la lame et les obstructions adjacentes est désirée afin de minimiser le niveau de bruit. La minimisation des émissions de bruit avait aussi un effet désirable sur l'analyse de la qualité du son.

1. INTRODUCTION

There have been marked improvements in the performance of computer graphic cards which obviates the need for cooling fans that can dissipate the increased rate of heat generation in the graphic processing chip. The use of a high-performance cooling fan also has the negative effect of the introduction of a new source of noise. This further complicates the performance and compliance requirements faced by the GPU card manufacturer.

As a first rule of thumb, it is preferable to use large, slowly rotating fans as opposed to smaller but faster rotating fans. The slower the fan speed, the less acoustic emission will result. However, care must be taken to maintain required cooling capacities, thus the careful balancing act between fan size and speed. To further complicate the issue, the available space due to form factor restrictions within the computer chassis is often limited. The space limitation, thus, prevents the implementation of large, low speed, high flow rate fans. Consequently, there is often little choice but to use smaller, higher speed fans operating in order too provide the required cooling capacity. The need then is to control the increased noise emissions.

Two fundamental mechanisms associated with the operation of a cooling fan cause the generation of noise. Both of these are sources of dynamic force variations between the surface of the fan blade and the immediate surrounding air.

The first of these is random generated noise produced at the fan inlet. If the inlet flow is turbulent, a force results which is dependant on the influence of the lifting force to the angle of attack [1]. Acoustic models which predict the generated sound power of this force can be readily found in aeroacoustic literature. The resulting amplitude of this random noise generation is directly dependant on the level of inlet turbulence. As such, the inlet path must be kept as unobstructed as possible to minimize the creation of any turbulence.

The second source of noise generation is caused by spatially fixed irregularities which can produce a wake in either the inlet or outlet flow. In the case of computer cooling solutions, these irregularities can be the result of either the presence of heat sink fins or an improperly designed shroud. The resulting dynamic forces can contribute to strong tones which are usually found at the blade passage frequency.

To lessen the impact of these mechanisms of noise generation, one can either modify the blades of the fan or lessen the impact of the irregularities on the flow. The first can be achieved through the implementation of airfoil shaped fan blades or the use of a variable depth volute. In this study, the latter of the two fixes was used. Here, the effect of the distance between the fan blade tips and the heat sink fins of a relatively simple video card cooling solution has on the acoustic emissions is experimentally investigated.

2.0 ACOUSTICAL MEASURES

A brief discussion of the fundamental acoustic parameters used in this investigation is presented in this section.

To measure the effectiveness of either of the above approaches, traditional acoustic measuring techniques and metrics are used to quantify the acoustic emissions. These include the determination of the emitted sound pressure level at a given distance as well as the radiated sound power level. Sound pressure level will be presented as A-weighted decibels, or dBA.

While A-weighting is the traditional analytical approach and serves well to quantify the amplitude of acoustic emissions, it offers no insight to the perceived quality of the sound produced by the graphic card cooling fans. Given this, the acoustic product evaluation of computer graphic card cooling noise should include sound quality or psychoacoustic analysis. Sound quality, as a product attribute, can significantly affect the acceptability or desirability to the consumer. Therefore, in order to truly determine the full acoustic impact that an active cooling solution will have on the end user, the measurement of the applicable psychoacoustic metrics is warranted.

For this investigation, measurements of loudness will be presented. While somewhat similar to the A-weighting scale discussed above, loudness is an ISO standardized metric which is a more detailed representation of how loud a source is perceived as opposed to a simply reported sound pressure level. The human body, head and outer ear act as spatial and spectral filters on an acoustic signal. The inner ear also imparts nonlinear characteristics on this signal which are not incorporated in a simple sound pressure level measurement. Compensation for the effect of temporal processing and audiological masking effects of sounds across the frequency range can be realized through the application of the calculated loudness metric in an acoustic measurement. The units of loudness are given as sones.

Also determined in this study is prominent tone (PR). This psychoacoustic metric gives an objective measure of the prominence of a tonal component of a measured sound. This metric is computed according to ANSI S1.13-1995. The prominent tone is defined as the ratio of the power of the critical (frequency) band centred on the tone under investigation to the mean power of the two adjacent critical bands. A tone is said to be prominent if its PR exceeds 7 dB and is usually reported along with the frequency at which it is located. For this investigation, only the presence of prominence will be indicated.

The acoustic testing was done in compliance to ECMA-74, "Measurement of Airborne Noise Emitted by Information Technology and Telecommunication Equipment" [2] and ISO 7779, "Measurement of Airborne Noise Emitted by Information Technology and Telecommunication Equipment" [3]. To further comply with these acoustic measurement standards, ISO 3745, "Determination of Sound Power Levels of Noise Sources" [4], was followed for the measurement and calculation of the sound power level

As part of the investigation, an uncertainty analysis was also performed. It was found that the measurement procedure produced an uncertainty level of less than 1 dB for the sound pressure level based results.

3.0 THE EXPERIMENT

The fan-sink design used has a 53 mm diameter fan and operates in a manner where the intake air is drawn in through and across the cooling fins located at the end and one side of the sink and is expelled out through the top of the fan. For this design, the GPU and memory modules are located beneath the cooling fins. The sink plate and fins are constructed of copper and have a polycarbonate shroud on the top side to direct the air flow through the fins. Figure 1 is a photo of the assembled fan-sink design.

In order to investigate the effect of varying distance between the fan and fins, a movable fin design was devised. This fin module was radiused to the contour of the impeller and was designed to be positioned at six different distances, from the tip of the fan blades. The distances used were 1 mm, 4 mm, 7 mm, 10 mm, 13 mm and 16 mm. Figures 2 and 3 illustrate the disassembled fan mount and movable fin module. The fan was operated at each of the six distances at three different speeds, each representing minimum, medium and maximum operational speed. Under normal operating conditions, the air mover speed would be controlled and varied based on the thermal load.

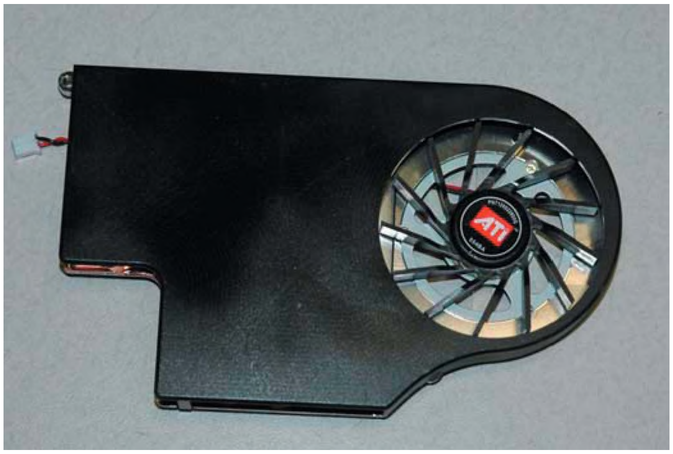

Figure 1. Assembled Video Card Fan-Sink Cooling Module.

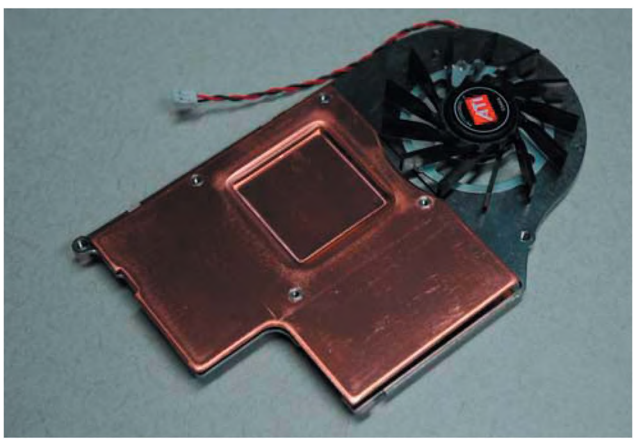

Figure 2. Disassembled Fan and Mounting Tray.

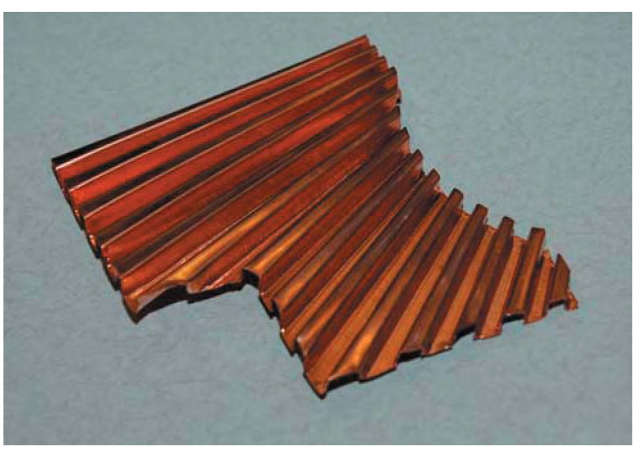

Figure 3. Movable Fin Module.

The acoustic measurements were conducted inside a hemi-anechoic room with an ambient noise level of approximately 17 dBA in the frequency range of interest. The determination of the sound power emission for each of the fan-fin distance variations involved the acquisition of ten free field sound pressure level measurements around the noise source in a specified hemi-spherical pattern which has a radius of 1 metre. The sound power level, reported as A-weighted Bells (BA) to comply with ECMA-74, is then calculated by taking a logarithmic average of these ten sound pressure levels and adjusting this to account for the surface area of the test sphere as well as atmospheric conditions and floor reflections.

Acquisition of the sound pressure levels and noise data used for the analysis of the psychoacoustic metrics were measured using a binaural head manikin at a distance of 0.5 metres. The manikin, which is shown in Figure 4, is a representation of a human head and torso with microphones mounted inside the artificial ear canals. The use of a binaural head for the acquisition data to be used for sound quality analysis is essential since the data is most representative of what would be perceived by an actual person.

Figure 4. Binaural Head Manikin used Acoustic Data Acquisition.

4.0 RESULTS AND DISCUSSION

Figure 5 illustrates the measured sound pressure level results of each fan-fin distance for each of the three measured speeds. An obvious pattern exists for each of the speeds. The sound pressure level is greatest for the 1 mm and 4 mm spacing between the fan tip and cooling fin. However, after the spacing is increased to 7 mm, the sound pressure level exhibits a rapid decline where it remains somewhat constant for subsequent larger spacings of 7 mm, 10 mm and 13 mm for this fan. For the 16 mm distance between the fan and fin another rapid decline in sound pressure level is realized. Inspection of Figures 6 and 7 for sound power level and Loudness respectively show very similar trends in the measured data.

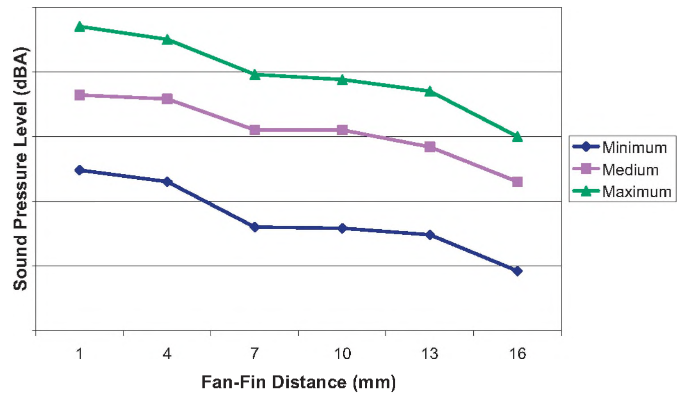

Figure 5. Measured Sound Pressure Level variation with distance.

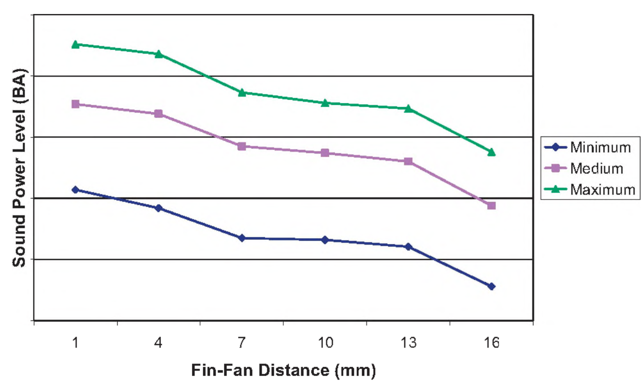

Figure 6. Calculated Sound Power Level variation with distance.

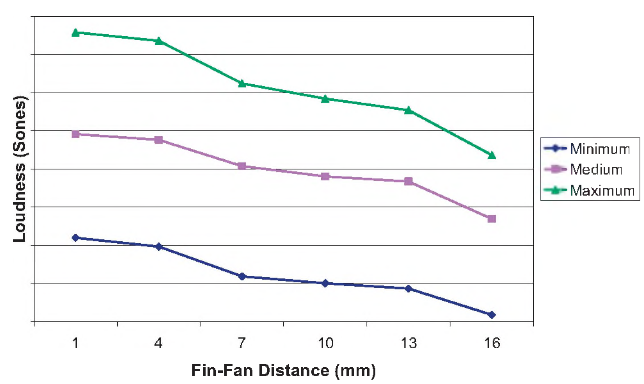

Figure 7. Calculated Loudness variation with distance.

For very close clearance spacing between the blade tip and cooling fin, it appears that a prominent mechanism of noise generation is present. This would account for the excess noise levels at the 1 mm and 4 mm clearance distances. Given that the length of cooling fins present on the intake side, it is a fairly safe assumption that the flow at the immediate exit would not be highly turbulent due to the flow straightening effect of the enclosed cooling fin channels. The noise generation would then be surmised to be the result of the presence of the spatially fixed irregularities in the very close proximity of the blade tips. This is further reinforced by the presence of prominent tones at the two closest distances as is shown in Table 1. What is not shown is that while some prominence was also detected at the 7 mm and 10 mm distances, the amplitudes of the tone were not as strong as the 1 mm and 4 mm cases. While this mechanism for noise generation can also be due to an interaction between the exit shroud and exhaust flow, this remained a constant for the entire study and therefore would play no role in the varying noise emissions. It should also be noted that the type of noise generation demonstrated here can at times also be controlled by other means. One way to accomplish this is through redesign of the fan blade. Examples of this include both the curvature of the blade as well an appropriate cross sectional profile. The latter of these two is more effective for larger diameter fans.

Table 1. Presence of Prominent Tone (Yes/No)

Distance (mm)	Minimum	Medium	Maximum
1	Yes	Yes	Yes
4	Yes	Yes	Yes
7	No	Yes	No
10	No	Yes	Yes
13	No	No	No
16	No	No	No

For the distances of 7 mm, 10 mm and 13 mm, an obvious reduction in noise emission is observed. Further, it is seen that the changes in noise level caused by the change in spacing are not very different from each other. It is suggested that the noise is created by a combination of both noise generation mechanisms. Inspection of Table 1 demonstrates a continued presence of prominent tones at the 7 mm and 10 mm distances. Therefore, the interaction of the cooling fins with the dynamic forces at the blade tips is still present. It should also be noted that, as the distance is increased, the flow straightening effect of the cooling fins is lessened. In other words, there is an increase in noise generation due to an increasing level of turbulence. From this it can be surmised that as the effect on the prominent tones is decreased with an increase in distance, this is offset by the noise generation due to increasing turbulence.

Once the cooling fins have been located at a distance of 15 mm from the fan, another drop in acoustic emissions is realized. It is suggested that at this distance, the effect of the fins as a fixed irregularity has been minimized and that the noise generation is now mostly due to the presence of turbulent flow.

5.0 SUMMARY AND CONCLUSIONS

Through the use of acoustic measurement and analysis techniques, it has been demonstrated that the generation and presence of acoustic emissions, for the particular cooling solution design considered, is the result of two mechanisms of noise generation. The first of these is due to the presence of turbulent flow and the second is from the creation of annoying prominent tones created by the presence of fixed irregularities in near proximity to the moving fan blades. From the presented results, it has been shown that a fine balancing act is necessary to minimize the noise emissions caused by these two mechanisms.

From the competing nature of these two affects, a simple solution derived from the location of the cooling fins with respect to the fan blade is not present. While it is obvious that a decrease in sound level is realized with increasing distance between the cooling fins and fan blades, a definitive decision of optimum distance can not be made in the absence of consideration of the required thermal performance of the heat removal system. Given this, other design considerations must also be considered for the control of noise. These include careful design of the fan rotor as well as the shroud used for flow directionality. However, the importance of clearance distance as one of the design considerations has been incontrovertibly demonstrated in this study.

ACKNOWLEDGEMENTS

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