EFFECT OF OBSTRUCTION NEAR FAN INLET ON FAN HEAT SINK PERFORMANCE

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ABSTRACT
Compact electronic enclosures requiring forced air cooling often have airflow obstructions located very close to the fan inlet. The adverse effects of these obstructions are not well understood even using modern CFD techniques. In this study a thorough experimental investigation was carried out on the thermal, airflow and acoustic effects of an obstruction very near to the fan inlet for four fan-heat sink combinations. It was found that as the obstruction was brought closer to fan inlet, the device case temperature increased significantly. This was due to a combined effect of reduction in the fan airflow and an increase in the fan inlet air temperature. The overall degradation in performance was more severe for obstruction heights less than 15mm. A reversal in the fan flow direction was observed for one fan when the obstruction was very close to the fan inlet (less than 7mm). The acoustic noise level (sound power) also went up for 3 of the 4 fan heat sinks which was partly due to an observed natural increase in the fan rotational speed. The thermal performance improved when the fan speed was artificially increased but with higher sound power levels.

KEY WORDS: fan heat sink interaction, heat sink thermal performance, sound power level, reverse fan flow, fan speed.

NOMENCLATURE

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Subscripts</th>
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<tbody>
<tr>
<td>CFM</td>
<td>airflow, cubic feet per minute</td>
<td>ca, th</td>
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<tr>
<td>F1, F2</td>
<td>fan 1 and 2</td>
<td>-</td>
</tr>
<tr>
<td>H</td>
<td>distance between fan inlet and obstruction (mm)</td>
<td>amb, c</td>
</tr>
<tr>
<td>HS1, HS2</td>
<td>heat sink 1 and 2</td>
<td>-</td>
</tr>
<tr>
<td>I</td>
<td>current, Ampere</td>
<td>-</td>
</tr>
<tr>
<td>PCB</td>
<td>printed circuit board</td>
<td>-</td>
</tr>
<tr>
<td>Q</td>
<td>device heat dissipation, W</td>
<td>-</td>
</tr>
<tr>
<td>R</td>
<td>thermal resistance</td>
<td>-</td>
</tr>
<tr>
<td>T</td>
<td>temperature, °C</td>
<td>-</td>
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<tr>
<td>V</td>
<td>voltage, V</td>
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Subscripts

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<tr>
<td>amb</td>
<td>ambient</td>
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<td>c</td>
<td>device case</td>
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INTRODUCTION
Fan-heat sink combinations are widely used in compact electronic systems where there is relatively high power density and small available space for cooling. They offer efficient heat removal with lower thermal resistances in a given space compared to passively cooled heat sinks. In fan heat sink combinations the fan flow can be either parallel or perpendicular to the heat sink base i.e. either side or impingement flow. The fan flow direction is selected based on heat sink geometry and system-level constraints so that the combination will offer a minimum thermal resistance. Thermal performance of a fan heat sink combination depends on fan characteristics (pressure/airflow capacity) as well as heat sink characteristics (pressure drop/thermal resistance). A heat sink performs differently with different fans [1]. It depends on conduction through heat sink and convection from fins. The heat sink geometry and material defines the conduction resistance which includes the heat spreading resistance in the base and the fin conduction resistance [2]. The Reynolds number between heat sink fins defines the convection resistance [3]. The convection resistance is also dependent on the airflow distribution between the fins which is a function of the geometry. Figure 1 shows a typical variation in the thermal performance graph of a heat sink with air velocity [4]. Normally the fan inlet section is kept very open so that...
air can enter freely. But in the case of some compact enclosures an obstruction may be placed very close to it. The presence of such an obstruction introduces additional pressure drop and can affect the fan airflow and thermal performance adversely.

In the present study, the schematic of the test setup used is shown in figure 2. The solid wall above the fan inlet represents either an adjacent circuit board, enclosure wall or any other system level airflow obstruction. A thorough experimental study is carried out to study effect of such an obstruction on the airflow, thermal and acoustic performance of the fan heat sinks.

To make the study more general, two different types of heat sinks and two different types of fans were selected to create 4 different fan heat sinks combinations. The heat sink geometries selected were straight bonded fin (HS1) and radial fin (HS2) shown in figure 3. Heat sink HS1 had an overall dimension of 70x80x40mm with a 5.8mm thick copper base, 43 number of 0.5mm thick aluminum fins having a fin pitch of 1.6mm. Heat sink HS2 had an overall dimension of 70x80x40mm with 72 number of 0.5mm aluminum radial fins soldered to a 27 mm copper core. The fans F1 and F2 were 70x70x15mm tube axial fans having a maximum flow/pressure of 37.4CFM/0.21in_water and 37.8CFM/0.22in_water respectively. The fan speed at 12V was 4300 for F1 and 3300 for F2.

**EXPERIMENTATION**

**Thermal Test Setup:**
Figure 4 shows the schematic of the thermal test setup with thermocouples used to measure the device case temperature and fan inlet air temperature. The thermal testing was done by using a thermal test vehicle (TTV) using a dummy chip in the form of a 15x15mm copper block with a resistance coil inside it. The fan heat sink was mounted using grease as the thermal interface material (TIM) and about 30 lbs of force. Using a DC power supply a fixed power of 60W was supplied and kept constant for all the tests. The temperatures at device case, $T_c$, and fan inlet, $T_{amb}$, were measured at different obstruction heights, $H$, at two different fan speeds. The results are reported in terms of $T_c$ instead of the case to ambient thermal resistance since the fan flow direction changed in some cases. The value $T_c$ was adjusted for a room ambient temperature of 30°C for all the cases.

**Airflow test setup:**
A wind tunnel was used to measure the airflow through the fan heat sink. The schematic of the wind tunnel is shown in figure 5. The wind tunnel used is a cylindrical tube with a bidirectional blower at one end and a test chamber at the other where the fan heat sink was mounted. The wind tunnel blower was configured to pull the air so that its flow direction is aligned with that of the fan heat sink and its speed is such that the pressure reading (P) downstream of the fan heat sink reads zero. The air flow through the wind tunnel was measured by reading the pressure differential (P1-P2) across the orifice plate located in the middle of the tunnel. This procedure was repeated for different obstruction heights (H).
Acoustic testing:

Testing was carried out to determine the sound power levels emitted by fan heat sink. This was done by measuring the sound intensity over a closed wire grid around the fan heat sink as shown in figure 6. The fan heat sink was placed on a hard surface so that it reflects the sound falling on it. The enclosing wire grid was divided into number of well defined small surfaces (cells) and the sound intensity was measured at the center of these cells by using a sound intensity probe. To ensure better accuracy, the measurement was done at night when the background noise level was low (especially intermittent noise). The sound power for each cell was calculated using

$$W = I x A$$  

where,

$W =$ sound power $W$

$I = $ sound intensity $W/m^2$

$A = $ area of the cell, $m^2$.

The total sound power emitted from the fan heat sink was calculated by adding the sound power of the cells. For each fan heat sink combination, the sound power levels were measured at four obstruction heights and two different fan speeds.

DISCUSSION OF RESULTS

All of the above testing (including thermal, airflow and acoustic) was carried out for 4 fan-heat sink combinations (HS1F1, HS1F2, HS2F1, HS2F2) at different obstruction heights $H$ and two different fan speeds.

Case and fan inlet temperature variation:

It was observed that the case temperature starts rising rapidly as the obstruction height $H$ becomes less than 15mm for the lower and higher fan speeds (Figure 7a and 7b). This is due to the combined effect of a reduction in the fan airflow (Figure 8a and 8b) and a rise in the fan inlet air temperature (Figure 7c). It appears from figure 7c that as the obstruction comes within 10mm of the fan inlet the hot exhaust air from heat sink re-circulates and mixes with fan inlet air. This hot air re-circulation becomes more and more significant as $H$ is reduced below 10mm. For $H$ at 5mm,
the fan inlet temperature rise accounts for 30-50% of the total case temperature rise. In the case of fan F1, the case temperature stops increasing for H less than 7mm. This is probably due to a reversal in the direction of the fan airflow which is discussed in more detail in the next section.

**Fan Airflow variation:**
Figure 8a and 8b shows the variation in fan flow rate with respect to obstruction height H at two fan speeds. As the obstruction is brought closer to fan inlet, the fan flow rate started to reduce. This reduction was found to be significant for H less than 15mm for all fan heat sinks tested. A reversal in the airflow direction was observed for fan F1 with obstruction heights less than 7mm. This phenomenon was not observed for the fan F2. This probably suggests that the flow pattern is dependent on other factors like fan speed and geometry. However, it should be noted that the accuracy of flow rate measurement reduces at low flow rates (< 5cfm). But the test data clearly shows that any obstruction placed within 15mm of the fan affect the flow rate adversely and the amount of reduction in flow rate is dependent on fan geometry.

**Sound power variation:**
For three of the four fan heat sink combinations it was
observed that the sound power levels increased as the obstruction was brought closer to the fan inlet (see figure 9a and 9b). This was partly due to the natural increase in fan rotational speed observed when the obstruction height was reduced (see figure 10). It should be noted, however, that the accuracy of the sound power measurement was low due to the relatively high level of background noise.

CONCLUSIONS
As expected, the results of this work show that the effect of having an obstruction very close to the fan inlet can have a strong adverse effect on the thermal and acoustic performance of fan heat sinks. For selected fan and heat sink combinations, for obstruction height H less than 15 mm, there was a significant rise in the device case temperature due to the reduction in fan flow rate combined with a rise in the inlet air temperature of the fan. The fan inlet temperature rise occurring due the hot air recirculation was very significant for H less than 10mm and accounted for 30-50% of the total case temperature rise at H of 5mm. The rise in the case temperature was found to be dependent on the fan type. While the case temperatures were almost identical for both fans at large obstruction heights, they were significantly lower for fan F1 when the obstruction height was less than 7mm. The acoustic noise was found to increase with reduction in the obstruction height due to an observed natural increase in the fan rotational speed. It is also clear that the thermal performance can be improved when the fan speed was artificially increased. However, this causes a significant increase in the acoustic noise.

REFERENCES
5. Brue & Kjaer, “Basic concepts of sound and basic frequency analysis”.