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Simulation and Analysis of Temperature Distribution and Material Properties Change of a Thermal Heat sink Undergoing Thermal Loading in a Mobile Computer.

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Abstract. This paper is aimed at studying the thermal distribution and its associated effects on a thermal heat sink of a mobile computer (laptop). Possible thermal effects are investigated using Finite-Element Method with the help of a FEM software (Ansys Workbench 14). Physical changes of the structure such as temperature change and deformation are measured and are used as the basis for comparison between models of heat sinks. This paper also attempts to study the effect of thermal loading on the materials found in a heat sink hardware in terms of stresses that may arise due to physical restraints in the hardware as well as provide an optimized solution to reduce its form factor in order to be comparable to an Ultrabook class heat-sink. An optimized solution is made based on a cylindrical fin concept.

1. Introduction

Advancement in microprocessor technology as well as manufacturing has enabled the Ultrabook class laptops to be developed. In essence, ultrabooks are mobile computers that are under 21mm thick hence offers a reduced form factor without compromising performance [1]. Comparing typical laptops and ultrabook laptops, an immediate distinction in terms of thermal management could be observed. Ultrabooks, by branding, runs on Intel's Central Processing Unit (CPU) chips and these chips produce a Thermal Design Power, TDP, of less than 15 W whereas typical laptops would use CPU chips that could have a TDP ranging anywhere between 11.5W up to 45W [2]. The TDP of a microprocessor is the thermal power that is generated by it and this is the amount of heat that needs to be rejected so that the microprocessor could function optimally.

The typical permissible operating temperature of the Central Processing Unit (CPU) is 70^{O}C and the reliability decreases by 10% for every increase of 2^{O}C [3]. Ergo, heat generated by CPU and Graphics Processing Unit (GPU) needs to be wicked away and this is achieved by using a heat sink hardware. The heat sink hardware consists of base plates, heat pipes, fins and a fan. At maximum operating conditions, the heat sink needs to be able to dissipate the thermal power generated. Smaller-sized mobile computers require a smaller heat sink assembly. Being smaller; the equivalent stresses in the unit may be higher. In order to study whether or not that is the case, this study also involves modelling a few conceps of heat sinks as well as simulating it at the operating conditions of the initial design.

Current heat sink technology are focussing on reduced dependencies on forced convection, advanced heat pipes as well as better performing and lighter weight materials [4] [5] [6] [7] [8] [9]. The inner workings of the heat pipe will be omitted in this study and will be assumed as a perfect heat conductor [10], conducting heat from the thermal plates to the heat sink fins.

As for the design of heat sink fins, there are two main school of thoughts, straight fins and cylindrical fins which are also known as pin fins [11] [12] [13] .Both have their unique strengths and weaknesses. This study will involve both designs

At elevated temperatures, thermally induced internal stress builds up within a member when it is unable to change length [14]. Material properties also differ at higher temperature as compared to

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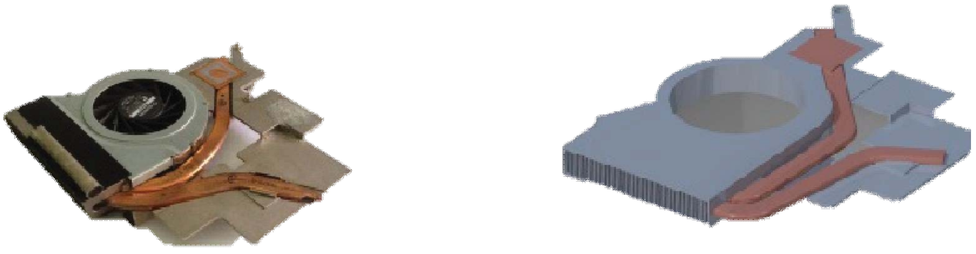
room temperature and for the most part, mechanical properties decrease with the increase of temperature [15] [14] [16] [17] [18] [19] [17] [18] [20].Seeing that a heat sink assembly is usually made up of more than one type of material, the Coefficient of Thermal Expansion (CTE) also plays a role in inducing stresses [21] .Creep is not considered for this study due to the operating temperature range being at a relatively low temperature ($<200^{O}$C). Creep only becomes significant at temperatures above 40% of the melting point temperature of the materials [22] [23].
This study will involve the analysis of 7 different models comprising of the initial model and 6 concept models. The table below explains the different characteristics of the concept models.

Table 1. Different physical characteristics of the concept models.

Model	Physical properties
Concept 1	Reduced values of w, H and L (refer toTable 2)
Concept 2	Similar size envelope to the initial model but with angled fins
Concept 3	Similar size envelope to the initial model but with cylindrical fins
Concept 4	Similar size to Concept 3 but with spacing between heat-pipe and fins.
Concept 5	Similar size and spacing as Concept 4 but with increased cylinder diameter,*d* (refer to**Error! Reference source not found.**)
Concept 6	Reduced values of w,H, L and hf and with same cylinder diameter and spacing as Concept 5 (Refer to **Error! Reference source not found.**)

For a similar size envelope, it is found that cylindrical fins could perform better than straight fins. A smaller size cylindrical fin was able to give the same performance as the original design. A cylindrical fin design would be smaller, lighter and material-wise, cheaper than the original design. This warrants further study into the total economic impact

2. Methodology



(a) (b)

Figure 1. Figure 1(a) is of the actual heat sink assembly and Figure 1(b) is the rendered image of the Creo Parametric model.

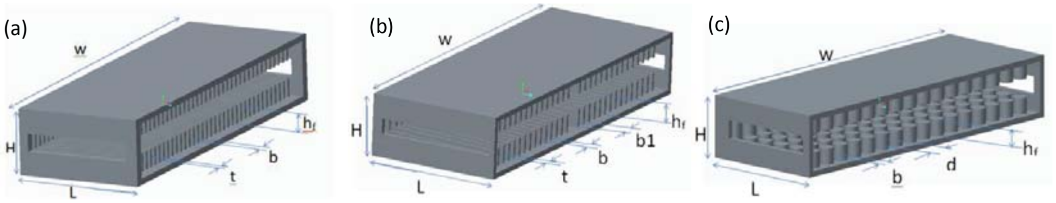


Figure 2. Figures 2(a), (b) and (c) shows where the letters are designated for the types of heat-sink design tested; t is the fin thickness, hf is the fin height and b is the spacing between the fins

Table 2. Shows the dimensions for each letter designation in the straight fin, angled fin and cylindrical fin design 2(a) and Figure 2(b) and 2(c)).

Model	**Straight fins**		**Angled fins**	**Cylindrical fins**			
	Initial	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Concept 6
w (mm)	67	55.5	67	67	67	67	59.5
H (mm)	12	11	12	12	12	12	11
L (mm)	26	21	26	26	26	26	22.2
t (mm	0.5	0.5	0.5	-	-	-	-
b (mm)	0.65	1	1.5	2.5	2.5	3.5	3.5
b1 (mm)	-	-	3.7	-	-	-	-
Theta (degrees)	-	-	85	-	-	-	-
hf (mm)	4	3	3.5	3.5	3.4	3.4	2.85
number of fins	55	35	30	225	225	108	80
d (mm)	-	-	-	1.5	1.5	2.5	2.5

1. The parts required for this study is modelled using Creo Parametric and the dimensions used for each part is listed in Table 2. Shows the dimensions for each letter designation in the straight fin, angled fin and cylindrical fin design 2(a) and Figure 2(b) and 2(c)).
2. Simulation is carried out using Ansys Workbench 14. For each simulation, heat is supplied to the fins by the heatpipes. Fixed constraints are at all of the outer wall of the fin body which is meant to emulate the fixed enclosure within a laptop.

3. Results

3.1 Volume reduction and material cost reduction

With reduced volume of materials put into the design, savings in cost could be made.

Table 3. Material Volume reduction in cubic milimeters.

	Material Volume (mm3)		Reduction in Volume
Model	Al	Cu	Al
Initial	8651.25	8558.48	0
Concept 1	4677.75	8558.48	3973.5
Concept 2	6612.45	8558.48	2038.8
Concept 3	7094	8558.48	1557.25
Concept 4	6961.26	8558.48	1689.99
Concept 5	8291	8558.48	360.25
Concept 6	5871	8558.48	2780.25

The reduced volume in turn reduces the mass of materials used. By finding out the mass of the material per unit of heat sink and finding the monetary value of the metals at current market price, a cost comparison between models can be made. All the concept models brought forward into this study are made of less material hence cost cheaper in terms of materials. A smaller heat-sink also translates to a lighter system.

3.2 Comparing simulation results

The maximum permissible stress of Aluminium is 610MPa [24]. As observed in the simulations, the initial design is well below the threshold. However, concepts 3 and 4 have a higher maximum stress which is experienced at the cylindrical fins. Even though the stress is higher, the maximum deformation in concept 3 is still lower than that of the initial design.

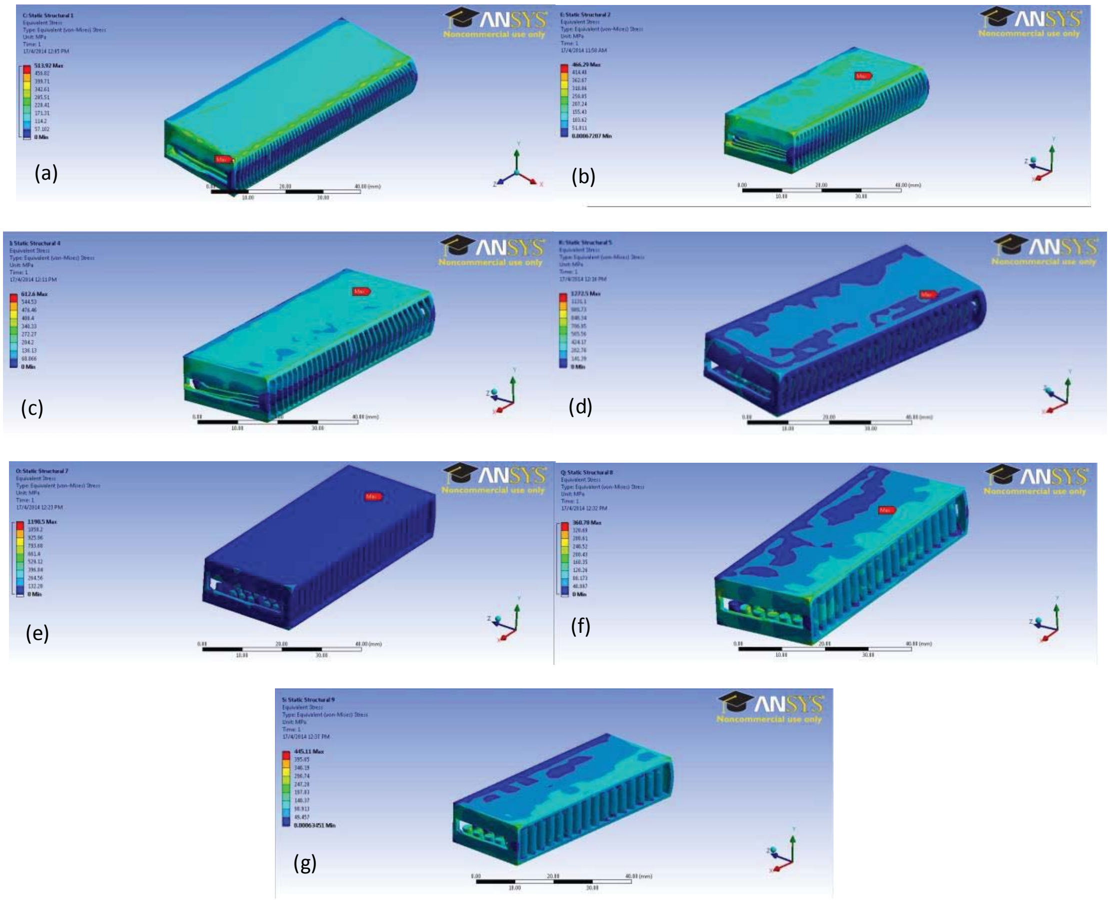


Figure 3 Distribution of stress levels experienced in the models from the first concept model (Figure 3(b)) to the sixth concept model (Figure 3(g).

Concept 5 and 6 is an attempt at reducing the stress levels in the cylindrical fins. This is achieved by using bigger-diameter cylinders. The stress is greatly reduced however the cooling capability is negatively impacted.

Table 4. Maximum stresses and deformation experienced in the models

Model	Maximum Stress (MPa)	Maximum Deformation (mm)
Initial	513.92	0.183
Concept 1	466.29	0.186
Concept 2	612.6	0.188
Concept 3	1272.5	0.181
Concept 4	1247.1	0.188
Concept 5	452.38	0.181
Concept 6	416.66	0.178

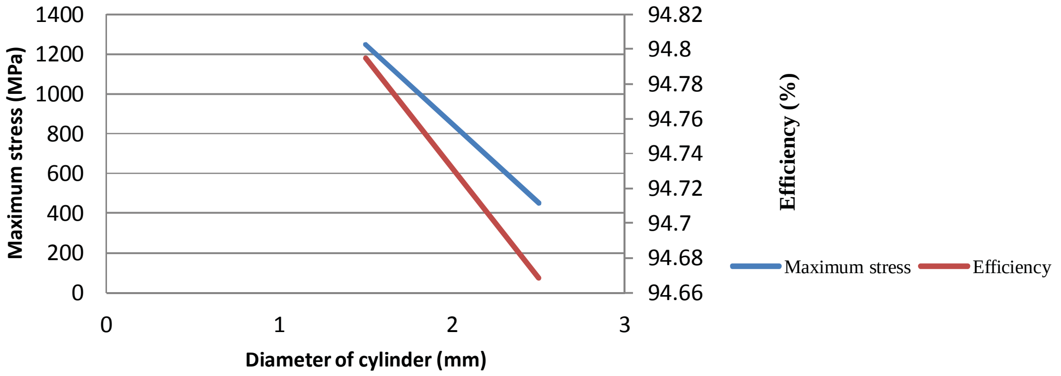


Figure 4. Relationship between cylinder diameter and the stress experienced and thermal efficiency

Trend lines are plotted using Concept model 4 and 5 in an attempt to find a compromise for a suitable cylinder diameter as shown in Figure 4. This results in efficiency higher than the initial model and at the lowest possible stress. Method of obtaining efficiency values will be explained in Section 3.3.

3.3 Formulating measure of comparison between heat-sinks

A measure of comparison based on the ratio of the temperature of the heat sink and the air temperature at the outlet is formulated:

$$\frac{\text{ı ıı ?ıı ıııııııı ?ı?ı ıııı}}{\text{ı ıııı ıı ?ıı ıııııııı ?ı?ııı}} \times \text{ııı} \qquad (\text{ı})$$

Table 5. Resultant efficiency of heat sinks based on alternative formulation

Model	Maximum temperature at fins (K)	Air temperature at outlet (K)	Comparison value
Initial	370.9	354.3	95.5244
Concept 1	369.7	352.8	95.42873
Concept 2	372.3	356.1	95.64867
Concept 3	373.7	366.2	97.99304
Concept 4	372.7	353.3	94.79474
Concept 5	369.5	349.8	94.66847
Concept 6	368.4	352.7	95.73833

In order to be deemed better than the initial product, the value at the Comparison column has to be of a higher value.

3.4 Cylindrical fins versus Straight fins

The elements that determine the cooling capability of any heat sinks include the surface area, metallurgy and the impact of the fin structure on the incoming air streams. Greater surface area and greater thermally conductive materials do make good heat sinks. However, the impact of the airflow is seldom looked at. Air acts as a good heat insulator if it is wrapped around a surface stagnantly. The function of heat sinks could then be thought of as a means to break the boundary layer by accelerating the air flow. Hence, a faster air stream would result in a higher probability that the boundary layer is broken which in turn results in a more effective heat sink [13].

That being said, the air velocity study at the outlet of all the models could act as gauge for comparison. All models are supplied with the same volumetric flow rate as dictated by the type of fan used. In each case, the same fan is assumed to be used and it supplies $3.28 \times 10^{1}\,{}^{1}\imath\ {}^{1}/\imath$ of air.

The Initial Model, Concept Model 2 and Concept Model 3 all have approximately the same air velocity at inlet. However, there are differences in the efficiency of those units. The table below serves as comparison of the velocities.

Table 6. Air velocities and resultant comparison value

Model	Inlet Air Velocity (m/s)	Maximum Outlet Air Velocity (m/s)	Comparison value (%)
Initial	5.07	15.5	95.52
Concept 2	5.05	17.3	95.64
Concept 3	5.05	27.5	97.99

The difference in cylindrical fin design greatly affects the air flow characteristics and in turn affects how effective the heat sink is.The observable stresses are higher in the cylindrical fin design than in the straight fins. This could be due to the greater temperature seen in the cylindrical fins main body. This higher temperature results in greater thermal stresses (Table 6, compare initial model with Concept 3 and 4). For the same amount of force exerted in the straight fins and the cylindrical fins, the stress levels differ according to the surface area. The smaller surface area of each individual cylindrical fins creates for a much higher stress. Because of this, the stress levels can be reduced by designing a heat-sink with bigger cylinder fins.

As for angled fins, the efficiency is higher compared to the initial design as the surface area that is in thermal contact is bigger. However, at angles approaching 0^{O} and 180^{O}, the fins would greatly affect the air flow. Once the fins are perpendicular lengthwise to the heat-pipes, the total surface area of the fins in contact with the airstream is minimal thus decreasing the efficiency of the heat sink.

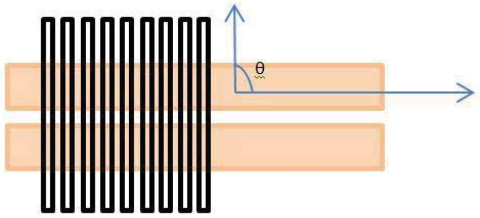


Figure 5. Reference angle for the case of angled fins

4. Conclusion

For a given size envelope, cylindrical fins have a higher efficiency when the cylinder fins are small (Figure 4). However, stress levels in cylindrical fin design are very high. A compromise needs to be made between cylinder diameter and the performance of the heat sink in terms of stress levels and efficiency.

This study has shown that a cylindrical fin design is cheaper, can be made smaller and has a better efficiency for a given size envelope compared to a straight fin design. After identifying a suitable diameter for the cylinder fins, possible limitations may only come from manufacturing methods that are employed in the industry to fabricate the fins. Assuming the cost of machining is higher than the typical straight fins, by economy of scale, the price could be justified reasonably as seeing it from the materials perspective it is actually cheaper. Concept 6 proves that a smaller form factor cylindrical heat-sink with a suitable fin diameter could work. Due to the reduced material needed, it is cheaper, lighter and smaller.

Possible improvement to heat sink design is to incorporate thermocouple materials to transform heat energy in the heat sink into usable electrical energy which could help power the fan in the system in order to improve battery life.

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