強制對流狀態下風速與鰭片數量對電腦散熱模組散熱現象之影響

江可達

摘 要

本文探討在強制對流狀態下其電腦散熱片模組中風扇所提供之風速與散熱片之鰭片數量對其散熱現象之影響，並透過其強制對流之流場速度分佈與散熱片之溫度場加以分析比較。本文中使用一套整合性之電子系統冷卻分析軟體來建構矩形平板散熱片之模型與四周空氣的強制對流之流場，藉以分析其散熱片的溫度場與透過強制對流之速度場了解其熱量傳導情形。所獲得之結果爲風速與鰭片數量之增加可降低散熱片的各項溫度值與熱阻抗值R(℃/W)，其遞減程度也有隨著其值增加而有減緩情形。但增加整個模組之鰭片數量時，使得其間隙之減少並影響其強制對流之流場。此外，散熱片模組之散熱能力，主要來自其模組上方風扇所提供冷卻的風量，若藉由流場造成壓力差而引入之外圍冷空氣，則有益於提升其模組之散熱能力。

關鍵詞：散熱片、強制對流、鰭片數量、風扇、熱阻抗值。

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Effect of wind speed and numbers of flake fin on the heat removal efficiency of a computer heat sink under forced convection

Ko-Ta Chiang

Abstract

The purpose of this paper is to study the effect of wind speed and numbers of flake fin for the influence of heat removal phenomenon in a computer heat sink under the force convection state and to analyze the results by means of the velocity distribution in the flow field as well as the temperature field of module. This study makes use of integrated analysis software of Electronic System Cooling to build the model of rectangular flat heat sink and analyzes the temperature field of the fin and the velocity filed of the forced convection to understand the state of heat conduction. The results show that increasing the wind velocity and the fin flakes will reduce both the temperature and the thermal resistance in the heat sink and the degree of decrease will retard. But increasing the amount of fin flakes will reduce the gap of fin flakes and effect the flow field of force convection. Beside, the cooling ability to heat sink module mainly comes from the wind capacity supplied with the electric fan above the module. It will benefit to the capability of heat removal, if pressure gradient in the flow field draws into ambient cold air.

Keywords: heat sink, forced convection, the amounts of flake fin, fan, the thermal resistance

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1. Introduction

Computer heat-sink design has become a significant issue in computer technology. The insufficient heat dissipate ability is a serious fatal wound for electronic device. In addition, the constant rising in computer technology, develop components into thin and tiny are in the trends. Developing orientation and guide principle are "Advance Integrated" and "To curtail the coil wire of crystals distance", also inclining to compact tight is the trend of structural design in the area of electronic device area. Increasing heat generation is the opposite of the reinforcing the power of Central Processing Unit, especially for the sake of increasing the speed and calculating capability of chipsets. Nevertheless without appropriate and efficient heat sink design, it will produce heat stress for chipsets, baseboard and sealed body. Nevertheless, it will critically affect the functions of chipset such as stability and lifetime, etc. Bar-Cohen and Kraus [1] discovered that the dependence and stability of chipset reduced by 10% if two degrees of centigrade of chipset is increased and over fifty percentage [2] of computer element failures are caused by this overheat problem. How can the dependence and long-lifetime of computer elements be assured through the most economic cost and efficient design to dissipate the heat expeditiously? Quality and competition of computer are consequent upon how to use exterior flow field, then, to analyze the heat dissipation and conduction that are generated by electronic element [3-7].

Modifying electronic element of geometry site on the main board to deal with natural convection and ability of heat transfer, or choosing forced convection to blow cold air across main board as fluid medium to obtain the optimum result of heat dissipation and cooling purpose are most common methods to take care with the problem of heat dissipation. Since the natural convection is not able to carry away enough heat, neither the forced convection generated by fan to blow air flow across the main board is dispersed nor centralized. Particularly, it can not afford the need of central processing unit - main source of heat loading unit. A heat sink attached directly to the central unit processor draws away heat, and a small fan attached in turn to the heat sink blows air onto the heat sink, dissipating the heat into the surrounding air. It is the way to handle upon problem. Designing the heat sink fin to play the substantial role is upon quantity of fins. The size of shape may influence the effect of convection and ability of heat dissipates for the heat transfer analysis. The higher rate of conduction has, the better conduction results for material. The conduction in sequence is Silver(410W/m℃), Cooper(385 W/m℃), Gold(295W/m℃), Aluminum (202W/m℃). In general to consider the Cooper or Aluminum as majority choice is for the heat sink fin, because the capitalized cost and weight are into account.

The fin's shape is limited by internal space; in addition to, surface area, amount of fins, gap distance, fin direction, or the full volume of heat sink fin, etc. are dealing with convection upgrade and strengthen heat dissipative ability. In the past, heat sink fin is regarded as two-dimensional rectangular plate for theory analysis [9-13] by the scholars, and the temporary state of conduction is connected with heat sink materials that are measured in "Biot Numbers" that increases in quantity. According to the heat loads and whether being enough to sway heat by the calculation of necessary airflow for the entire specific system, it also prevents overheat under the permit of temperature raising range. According to the conditions that heat loading and weather sway enough thermal by the necessary dissipative airflow amount for specific system, and prevent overheat of system happen under the permit of temperature raising range to chosen an electric fan. Efficiency of thermal dissipation level is influenced by the fan mounting location, shape size of heat sink through the three dimensional turbulent current produced in the forced convection airflow field that is caused by the fan. Maximum temperature occurred within the radius of hub as electric fan tightly close to the top end of heat sink center. According to the result of experiment made by Wirtz, Sohal, and Wang [14] that the weakest heat dissipative phenomenon is just within the radius of hub of electric fan. In fact, adjusting the mounted angle of fan and distance between fan and heat sink can promote the ability of heat dissipation.

From the analysis of the previous works, there have been close correlations between the ability of heat dissipative module for central processing unit, shape configuration of heat sink, and selection of electric fan. This article investigates the wind velocity supplied by the electric fan and amounts of heat sink fin for the influence of thermal dissipative phenomenon in a computer heat sink under the forced convection state and analyzes the results by means of the velocity distribution in the airflow field as well as the thermal field of module. In order to get imitation and explanation to assist analyze the thermal field and velocity field of whole module, coordinated meshing assistant model that supported by the Electronic System Cooling software [15] as well as integrate software I-Deas Master Series 8 of CAD/ CAM/ CAE/CAT are used. This analysis software provides an enormous figure and bond with hydrodynamics current fluid dynamic technology and heat dynamic technology to be able precisely imitate the complicated curved surface qualities, such as convection, conduction, radiation, heat, etc.

2. Mathematic formula

The computer heat sink module geometry is shown in Figure 1. The basic presume conditions for heat sink module mounted onto the center processor unit as following:

1. To set up air as a fluid medium and the Newtonian Fluid fluid.
2. Three-dimensional turbulent flow

state.

3. Ignore the Radiation effect.
4. None thermal source from the heat sink and the base bounded by the equivalent thermal rate from the running center processor unit chipset.

Secondary, it sets up the physical module of surrounding fluid field of flat heat sink fin, for the purpose to comprehend the heat transfer capacity that transfer by fluid field. Found a rectangle space that above the center processor unit in a computer. Governing equations for turbulent condition to describe by time average value for the Continuity Equation, Momentum Equation, and Energy Equation as following [16]:

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho u_j)}{\partial x_j}=0 \tag{1}$$

$$\frac{\partial(\rho u_i)}{\partial t}+\frac{\partial(\rho u_j u_i)}{\partial x_j}=-\frac{\partial P}{\partial x_i}-\frac{\partial \tau_{ij}}{\partial x_j}+S_{ui} \tag{2}$$

$$\frac{\partial(\rho E)}{\partial t}-\frac{\partial(\rho u_j H)}{\partial x_j}=\frac{\partial q_j}{\partial x_j}+S_E \tag{3}$$

where u_i is the velocity in the x_i coordinate direction, P and τ_{ij} is the static pressure and the viscous stress tensor, q_i is the energy transport due to conduction, S_{ui} and S_E are the additional source term for momentum and energy respectively. E and H are respectively the total energy and enthalpy, defined as

$$E=e+\frac{u_i u_i}{2} \tag{4}$$

$$H=h+\frac{u_i u_i}{2} \tag{5}$$

where e and h are the internal energy and static enthalpy respectively. To calculate the convecting faces and convective conductances from the thermal model to the faces of the flow model using

$$q=h_{i-j}A_{i-j}(T_i-T_j) \tag{6}$$

where A_{i-j} is the overlapping area between the two elements and T_i, T_j ,are the local surface and fluid temperature respectively, h_{i-j} is the local adiabatic convective heat transfer coefficient form surface element I to near fluid element J . The local heat transfer coefficient h_{i-j} is derived from a near-wall function using Reynolds analogy which is a derivative of that of Kader [17]. The local heat transfer coefficient is calculated by use of the local distribution velocities, shear stresses and other turbulence quantities in the near-wall region.

3. Numerical procedure

First, it uses thin shell factor of 3-node tetrahedral as the base to set up meshing for heat sink fin. The base was controlled by the equivalent thermal rate from the running center processor unit chipset. The next, it uses substantiality element of 4-node tetrahedral to produce the meshing for heat sink, after that meshing the fluid field of forced convection that generated by fan and surrounding the heat sink. In the mean time to combine both meshing and element that is set up by heat sink and surrounding air.

For the reason of accuracy in the dimension of meshing, thus the element chosen has been segment and compare repeatedly. The space is open and within the compass of length 150mm, width 150mm, and high 24mm to analyze the forced convection fluid field that is surrounding the heat sink after generated by electric fan. To set up the meshing and element for fan that is upon the heat sink by using 3-node tetrahedral shape thin shell. The geometry and the element for whole module are shown in Figure 2.

Definition by setting up the convergent condition in this temperature field of heat sink fin and the velocity in this forced convection field as following:

The convergent condition for thermal field of rectangular flat heat sink

$$\left|\frac{T^{n+1}-T^{n}}{T^{n+1}}\right|_{\max} < 10^{-6} \qquad (7)$$

The convergent condition for surrounding thermal field, fluid field velocity of rectangular flat heat sink

$$\left|\frac{T^{*n+1}-T^{*n}}{T^{*n+1}}\right|_{\max} < 10^{-6} \qquad (8)$$

$$\mathrm{Max}\left(\left|u^{n+1}-u^{n}\right|, \left|v^{n+1}-v^{n}\right|, \left|w^{n+1}-w^{n}\right|\right) < 10^{-6} \quad \text{for air} \qquad (9)$$

4. Results and discussion

To determine whether the heat sink module design being able to reach its' optimum state can be done by judging the level of thermal carried away by the forced convection fluid field, after the thermal conducted from center processor unit chipsets.

First of all, in this investigation according to the value of thermal field distribution and maximum temperature of flake fin in as consult data, and calculate the thermal resistance value *R* (℃/W). The next, it analyzes fluid field condition of forced convection, highest velocity, and cold airflow in this open space. Not only the cold air-flow blowing into the heat sink, the electric fan also build up the optimum state of heat sink module which was designed to carry thermal away, in addition the cold air-flow is brought by the forced convection. Only if no more thermal gather in the heat sink fin and bottom that the thermal field distribution range of flake fin of heat sink module will tend to lower the temperature's phenomenon.

From upon analysis of heat dissipation progress, the heat dissipation module and shape design of surface area are counted on the heat dissipation ability and the amounts of heat sink flake fin; those are dealing with close connection. In addition to those factors, whether the airflow that produced by the electric fan is affordable to carry the thermal away from the heat dissipation-taking place without a hitch. This investigation is trying to find out heat dissipation ability and analyze the correlation between thermal field of heat sink fin and velocity profile of velocity field that influence by the forced convection through amounts of flake fin and the airflow velocity provided by electric fan. We set up four composes of variety heat sink modules as our research objects; the amounts of fin, size of shape, volume and surface area as listed on Table 1. The material is Aluminum Alloy (AL6063), thermal conductivity coefficient K is 192.13W/m℃, Environment Reference temperature T_0^* set up as 30℃ , atmosphere pressure is 101.35 *kPa*. Air is the medium of heat dissipation fluid. Normal airflow blow current across the heat sink modules is arranged by six varieties of speed from 5*m/s* to 30*m/s*. This thermal power is set at 40 W when the heat sink bottom contacted with central processing unit chipsets; varieties of central processing units and clock frequencies have different thermal power.

4.1 Analysis of velocity field and thermal field for the heat sink module.

First, analyze the variation of thermal field and velocity field as blow airflow across 9 flake fin of heat sink by 20 m/s velocity of electric fan. As shown in Figure 3-A, velocity Profile as electric fan created forced convection. It has shown less airflow amount within the radius of fan-hub and cold air that is drawing to the right and left sides of the heat sink. From Figure 3-B, obvious phenomenon is shown that air is drawing to the right and left side of exterior fin, because of the air pressure distance between the interior and exterior heat sink, which allowed the cold airflow to ambient the temperature by draw to the two sides as well as the fan blowing the air from the middle to two sides on normal directions. Furthermore, because of the airflow is generated within from inner to outer radius of fan, it caused two sides received more airflow amount than the middle of heat sink flake fin. As shown in Figure 4-A, B to improve that two sides of heat sink flake fin under the inner and outer radius received more amount of airflow than the middle of heat sink flake fin underneath to the fan hub received comparatively less amount of airflow. On the other hand, the thermal variation of heat sink fin has obviously correlation with airflow amount that the more airflow the lower temperature of fin contained. As shown in Figure 5-A, Temperature of fins within the radius is increased from inner to outer. Highest thermal distributed at the location that heat sink underneath the fan hub. For the thermal field, the temperature increased from the top to the bottom elucidates the thermal conducted from the base of module of heat sink to each fin. Figure 5-B Thermal field elucidate the predication that in the middle base of heat sink that just under the inner radius received the least airflow amount.

4.2 Airflow velocity effect

Heat dissipation phenomenon is under the aegis airflow field of forced convection react on the surface of each flake fin. Heat dissipation effect is relied on the carrying the ability of airflow field that generated by convective thermal transmission between two fins. In Figure 6, nine pieces of fin of heat sink module tested by six airflow velocities. Thermal area diminished on account of increasing airflow velocity. The thermal area is abating apparently declined from 90.858℃ to 83.703℃ before reaching to 20m/s airflow velocity, but only abated from 47.279℃ to 40.542℃ after raising airflow velocity to 30m/s. The temperature decrease by degrees in the thermal field has its utmost. As Table 2 listed, describe the data in the Lowest Temperature , Highest Temperature , Temperature Difference, Average Temperature, and Thermal Resistance *R* (℃/W) etc. As shown in Figure 7 Analysis for the variation on highest thermal value of heat sink fin. Predicting the phenomenon that thermal would not abated to ultimate value, as to generate the fan to six expectant velocities, as the thermal value is not decrease by degrees anymore. How to comprehend the decrease by degrees of thermal value as increasing the generation of airflow velocity by taking highest temperature of four modules at 5m/s airflow velocity? The degree of abatement only got 6.3%, 5.2%, 4.6%, and 4.0% once developed the velocity to reach 30m/s. Before the velocity of 20m/s, the degree of abatement for this four modules reached to the highest temperature are 41.7%, 35.4%, 28.0%, and 25.8%. In addition to the degree of convective thermal transmission has reached to its' maximum value as the airflow velocity reached to some level to transport the thermal amount (capacity) by airflow field. The thermal dissipation ability will reach to the bond that only generated by electric fan.

4.3 The effect of dealing with amount of flake fin of heat sink

Upon the conclusions, to reach the maximum level of convective thermal transmission is the promotion of related factors between airflow field and surface of flake fin. By raising or abating the amounts of flake fin is the utmost easy route to increase or decrease the heat dissipative area. As list in Table 1 in the meantime raising the flake fin number to increase the surface area, change the forced convection as well. Figure 8 has shown four modules running by 20m/s airflow velocity of electric fan. The velocity field that under the fan within the inner and outer radius that increment is 38.17%, because the velocity is advanced from the value 28.935m/s to 39.981m/s. Under the same amount of airflow, velocity value promoted only due to short the distance of gap between fins after raised the flake fin numbers. Furthermore, thermal dissipate ability is improved because of increased two sides on the right and left ambit cold air is evaluated by the velocity value followed by shorten the middle gap distance of whole modules. As shown in Figure 9, thermal field variation after raise the amounts of flake fin, thermal field was abated from high thermal field (52.973℃~46.058℃) to low thermal field (38.868℃~36.855℃)

As raised the amounts of flake fin, as well as the variety thermal value and thermal resistance value *R*(℃/W) etc., the value was decrease by degrees. How to relate the heat dissipation field and decrease by degrees of high temperature after raise the flake fin numbers under the basis of utmost thermal field (52.973℃) of nine pieces of flake fin module blown by airflow in 20m/s velocity? Raising four flake fin numbers is as one unit and for each unit is 2,142mm^2. The total surface area will increase by 8,568mm^2. The highest thermal decrease by degrees is 14.44%、8.09%、6.70%. In fact, under the consideration of minimum gape distance is the reason of limitation of flake fin numbers. The thermal value do not declined anymore when increasing the flake fin to its' ultimate number, because the gape distances between two fins for the four modules decreased in series by 5.125mm^2, 3.083mm^2, 2.063mm^2, and 1.450mm^2. Airflow section area abated caused by variety of the forced convection airflow field.

5. Conclusions

Comprehend the analysis of the airflow velocity supplied by fan and amounts of flake fin for the influence of thermal dissipative phenomenon in the state and analyze the results by the forced convection distribution in the airflow field as well as the thermal field module. The results are as following:

1. The level of thermal transmission of the surface area with the airflow field reached to its maximum value as against abating the variety of thermal value as well as resistance value R (℃/W) on flake fin after increasing the wind velocity of fan.
2. The thermal field will in stable at the low temperature state as when increasing thermal dissipation area by raise the amounts of flake fin for each module. Variety of thermal and resistance value R(℃/W) decrease by degrees, and slow down the level of decrease by raising flake fin numbers.
3. To change the forced convective airflow field through shorten gape distance by increasing the amount of flake fin.
4. Majority thermal dissipation ability for these modules are came from the cooling airflow caused by the atmosphere pressure distance to bring ambit air through upon electric fans. If different pressures of flow field attract outside of

cooling air, it can promote the capability of heat removal module.

For the sake of uniform diffuses the amount of heat and avoids the appearance of centralizing heat on the base of heat sink module, we will take the effect of copper bottom in the base of module for the effective of heat removal capability as future work.

NOMENCLATURE

A	overlapping area
e	internal energy of the fluid
E	total energy
h_{i-j}	local heat transfer coefficient
h	static enthalpy of the fluid
H	total enthalpy
P	static pressure
q_j	energy transport due to conduction
S_{ui}	additional source term for momentum
S_E	additional source term for energy
T	temperature
t	time
u_i	velocity in the x_i direction

Greek symbols

ρ	density
τ_{ij}	viscous stress tensor

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Table 1: Amount of flake fin, appearance, volume and surface area of heat sink module

Module	Amount of fin	Size(mm)	Volume	Surface area
1	9	50x50x23	14550	22382
2	13	50x50x23	18750	30950
3	17	50x50x23	22950	39518
4	21	50x50x23	27150	48086

PS: surface area(not including base area)，each size for flake fin 50x1x23 mm。

Table 2: Variety of data under tested by six airflow velocity of four modules

module	9 Flake Fins				
velocity	T_{max}	T_{min}	T_{ave}	ΔT	R(℃/W)
5	90.858	83.703	87.404	7.155	1.435
10	68.979	61.975	65.566	7.004	0.889
15	58.608	51.632	55.195	6.976	0.630
20	52.973	46.058	49.565	6.915	0.489
25	49.556	42.726	46.160	6.830	0.404
30	47.279	40.542	43.900	6.737	0.348
module	13 Flake Fins				
velocity	T_{max}	T_{min}	T_{ave}	ΔT	R(℃/W)
5	70.149	64.740	67.236	5.409	0.931
10	55.282	49.850	52.364	5.432	0.559
15	48.860	43.468	45.949	5.392	0.399
20	45.326	40.028	42.433	5.298	0.311
25	43.142	37.946	40.270	5.196	0.257
30	41.666	36.563	38.815	5.103	0.220
module	17 Flake Fins				
velocity	T_{max}	T_{min}	T_{ave}	ΔT	R(℃/W)
5	60.504	56.069	58.037	4.435	0.701
10	49.394	45.027	49.956	4.367	0.499
15	44.380	40.023	41.942	4.357	0.299
20	41.658	37.362	39.228	4.296	0.231
25	40.002	35.784	37.585	4.218	0.190
30	38.895	34.755	36.493	4.140	0.162
module	21 Flake Fins				
velocity	T_{max}	T_{min}	T_{ave}	ΔT	R(℃/W)
5	52.390	48.677	50.328	3.713	0.508
10	44.354	40.805	42.321	3.549	0.308
15	40.873	37.349	38.852	3.524	0.221
20	38.868	35.384	36.855	3.484	0.171
25	37.611	34.183	35.609	3.428	0.140
30	36.761	33.395	34.771	3.366	0.119

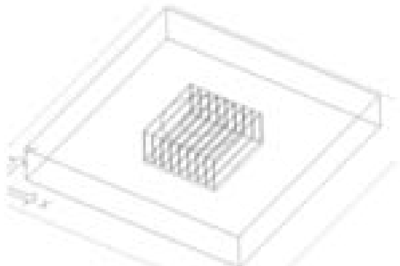


Figure 1: Heat sink module of physical model.

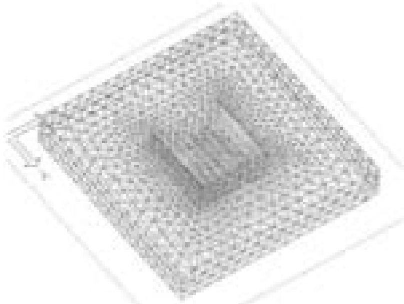


Figure 2, The geometry of meshing and the element for whole module

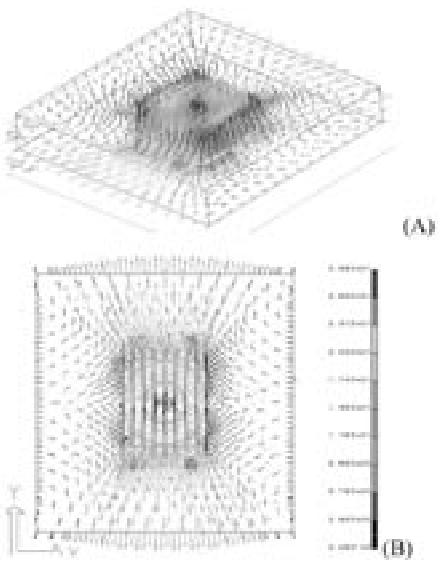


Figure 3: 9 flake fins of heat sink of airflow profile forced convection field of surroundings air

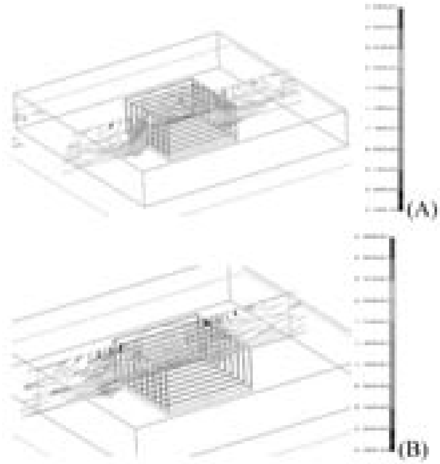


Figure 4: 9 flake fins of heat sink module of (A) the middle and (B) profile velocity of inner and outer radius of airflow

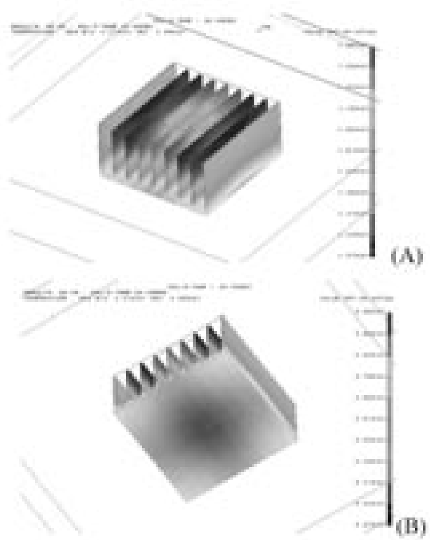
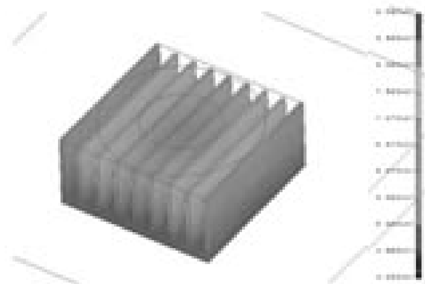
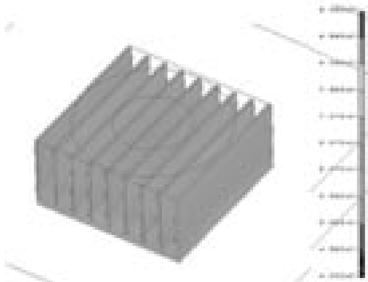


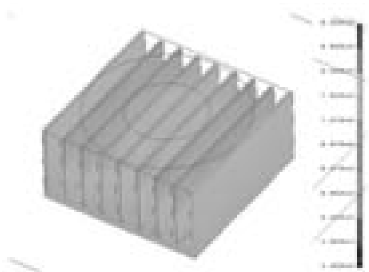
Figure 5: Thermal filed profile of 9 flake sink module.



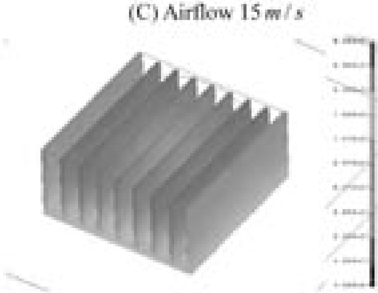
(A)Airflow 5 m/s



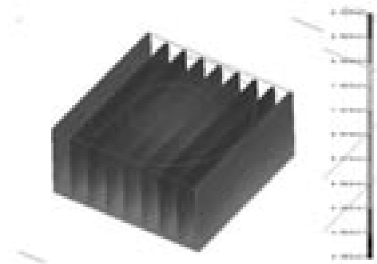
(B) Airflow 10 m/s



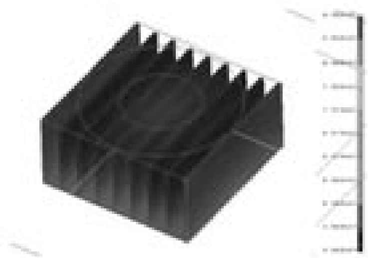
(C) Airflow 15 m/s



(D) Airflow 20 m/s



(E) Airflow 25 m/s



(F) Airflow 30 m/s

Figure 6: Thermal filed profile of 9 flake sink modules between airflow 5 m/s and 30 m/s.

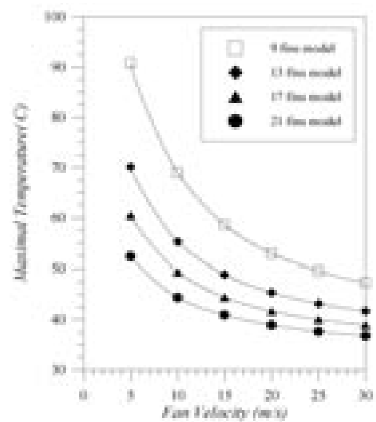
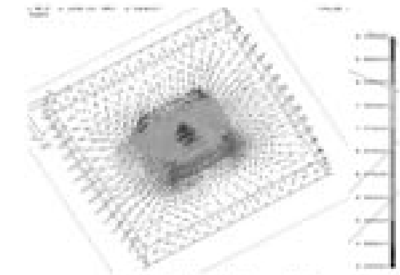
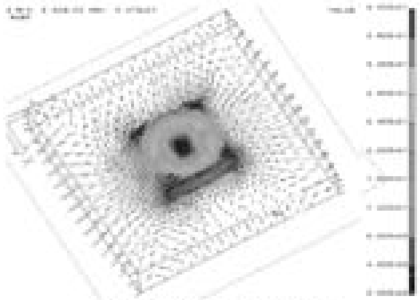


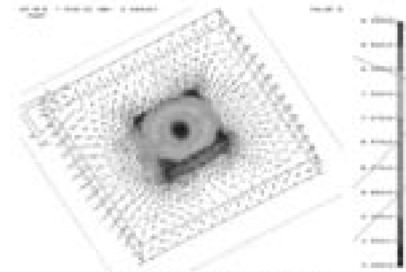
Figure 7: The maximum temperature variation as airflow changes in the 4 modules.



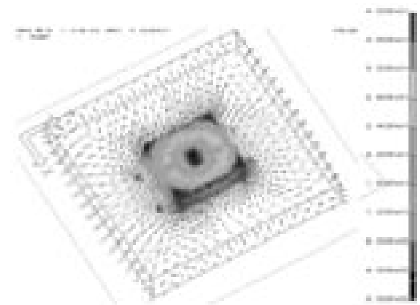
(A) 9 flake sink module



(B) 13 flake sink module

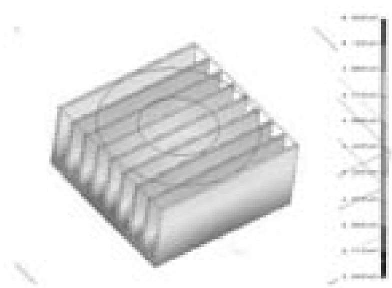


(C) 17 flake sink module

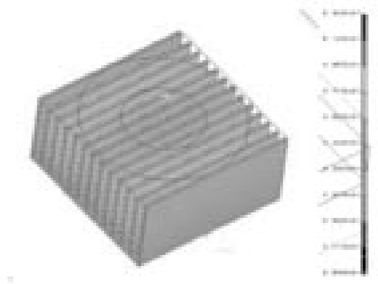


(D) 21 flake sink module

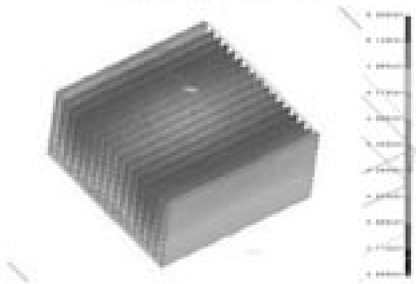
Figure 8: Under 20 *m/s* of airflow, each heat sink for forced convection of the field speed distribution.



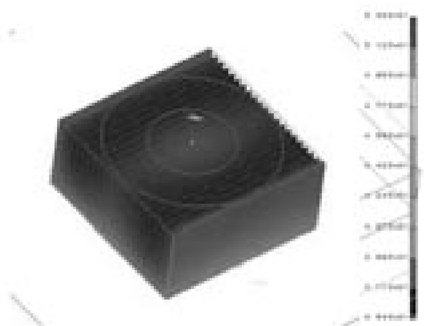
(A) 9 flake sink module



(B) 13 flake sink module



(C) 17 flake sink module



(D) 21 flake sink module

Figure 9: Under 20 *m/s* of airflow, thermal filed of each heat sink module.