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Analysis of Special-Purpose Computer on Temperature Field and Optimization Design

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A special-purpose computer has a fully enclosed structure. Values of internal temperature often increase for a hermetic case, and the work stability would be weakened. Software Flotherm is used to conduct the analysis of thermal simulations. In this paper, a computational model is established, and the flow process inside the main case is simulated. The temperature distributions of the main case and the motherboard are obtained, and testing experiments are also conducted. Results show that the numerical simulations are almost the same as the experimental results. The simulation model is confirmed accurately, which provides theoretical basis for the design of special-purpose computers. Meanwhile, the cooling structure of the printed circuit board (PCB) is optimized. Compared with the case before the optimization, the optimized cooling structure shows an enhancement of the heat dissipation.

1. Introduction

With the rapid development of modern technologies, various electronic technologies have been widely used in military and civil fields. Electronic equipment shows a trend of miniaturization, and thermal reliability is particularly important for the frontier of product designs. Klemes et al. (2013) discussed that the efficiency of the heat recuperation plays an important role in settling the problem of greenhouse gas emissions. Gough et al. (2013) presented that heat transfer enhancement substantially facilitates the solution of this problem. Nowadays, numerical methods are always used to replace experimental investigations which needs more financial resources and time-cost. Oberkampf et al. (2013) pointed out problems about the accuracy of computations. Wernik et al. (2015) conducted a study by using thermovision instruments to validate the computational accuracy of numerical models. By using both numerical simulations and experimental studies, Wernik et al. (2016) investigated heat conduction in a finned channel. The numerical method showed reasonable and accurate results.
The purpose of this paper is to investigate the enclosed chassis structure and the thermal design on special-purpose computer in detail. Accurate numerical simulations are performed by software FLOTHERM.

2. Calculation model

2.1 Geometric model

Components of a special-purpose computer are divided into two parts: One part is the heating components, including power supply, motherboard and interface board; the other part is the structural components, including rear panel, the upper and lower guide plates, side panels, small panels, large panels, heat sink and cooling fans. The board is modelled with detailed structural modelling. Since the chassis is aluminium vacuum welded, there is a reliable heat transfer path between the corrugated plate and the upper and lower cover plates. The computational model can be simplified as follows:

i. The heat sink is ignored for many configurations, such as chassis side panel, facets on outside surface of the chassis and instrument panel mounting holes.
ii. The thermal contact resistance is not considered, although the lower cover can be regarded as a radiator of the substrate.
iii. Other things are included: the damping caused by the cable inside the device, the power consumption of

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the cable inside the device during work, small devices inside the device (such as screws, studs, positioning blocks, gaskets, alignment boards, aviation slots).

The chassis is simplified as shown in Figure 1 And the motherboard is simplified as shown in Figure 2.

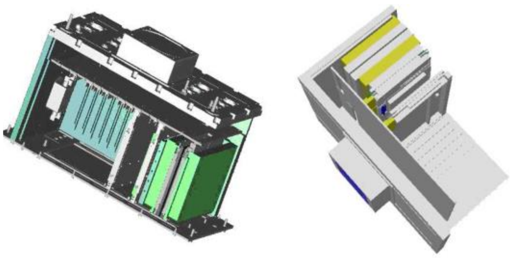

Figure 1: Simplified model of the chassis.

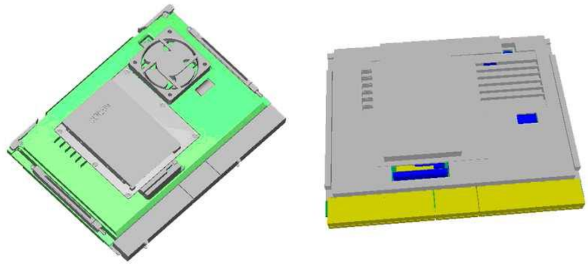

Figure 2: Simplified model of the motherboard.

2.2 Boundary condition

The outside of chassis is equipped with a fan, so the external air flow is forced convection. The heat transfer coefficient between air is 5 W/m^2·K. The ambient temperature is 308 K, and the pressure is 1 atm. Air physical properties at 308 K is shown as Table 1. The computational domain of the system is about 2.5 times as the box volume, direction of gravity is the positive X direction as shown in Figure 3. The system has nine heating elements, and the total power consumption is 118 W. The distribution of power consumption is shown in Table 2. The distribution map of main board components is shown in Figure 4. LY12 constitute the upper and lower guide plates, the cooling board and the size panel. The core heat sink of the power supply is made of 2A12, and the PCB board is the circuit board substrate FR4 with the copper clad rate of 20 %.

Table 1: Air physical properties at 308 K.

T(K)	$\rho(kg/m^3)$	$c_p(kJ/(kg\cdot{}^0C))$	$\lambda\cdot 10^2(W/(m\cdot K))$	$\mu\cdot 10^6(kg/(m\cdot s))$
308	1.1465	1.013	2.716	18.9

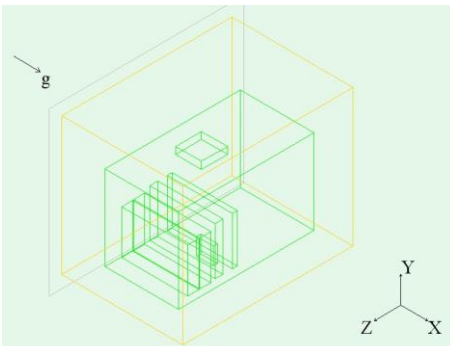

Figure 3: The schematic diagram of the solution domain.

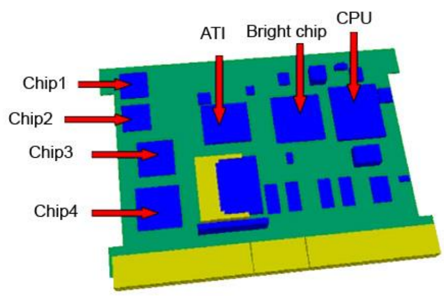

Figure 4: The distribution map of main board.

Table 2: The power consumption of components.

Components	Source1	Source2	CPU	ATI	Bright chip	Chip1	Chip2	Chip3	Chip4
Heat consumption(W)	40	40	15	12	3	2	2	2	2

2.3 Meshing

To save the analysis time and keep the accuracy of calculation, the maximal grid aspect ratio is (57.5). But the thickness of the system is relatively small, partial division like the motherboard is used to obtain a dense grid meshes. High-power elements exist in the system, so the heat distribution within the computational domain is non-uniform as shown in Figure 5. The number of grid cells for this model is about 1.76×10^6.

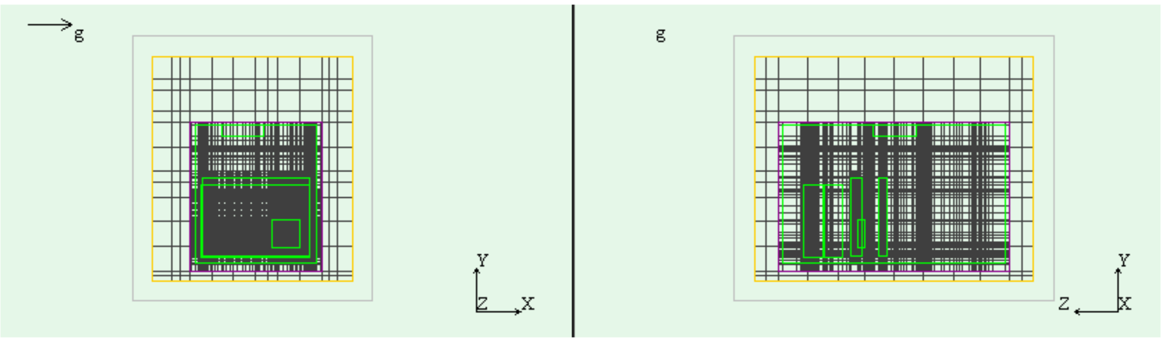

Figure 5: Grid meshing

3. Experimental verification

The special-purpose computer was placed in a box with a constant environment temperature of 308 K. After an operating time of 2 h, the measurements were conducted with K-type thermocouples by analysing the temperature values on CPU, outer surface of the power, the centre of the chassis and other four positions (Chip1, Chip2, Chip3 and Chip4). The measured data and simulated results are shown in Table 3 and Figure 6. The results show that the simulated results are slightly higher than the measured values by using the thermocouples. The maximal deviation is 8.5 % and the minimal deviation is 1.8 %. The hottest point monitored on the motherboard is Chip1. This is because the Chip1 is far away from the main board with ventilation holes compared to the other points of Chip2, Chip3 and Chip4. There are small air flows, high thermal resistance, and high-power density for the position of the Chip1. Due to the high-power density of the components, the temperature of CPU is high.

Table 3: The results of thermal simulation and thermal measurement.

Measuring point	Simulation Results (K)	Experiment Results (K)	Relative error (%)
Chip1	350.7	346.6	5.57
Chip2	348.4	342.5	8.48
Chip3	344.8	340.1	7.07
Chip4	340.2	337.3	4.67
Power outside surface	329.9	326.7	5.96
Chassis centre	318.1	317.3	1.80

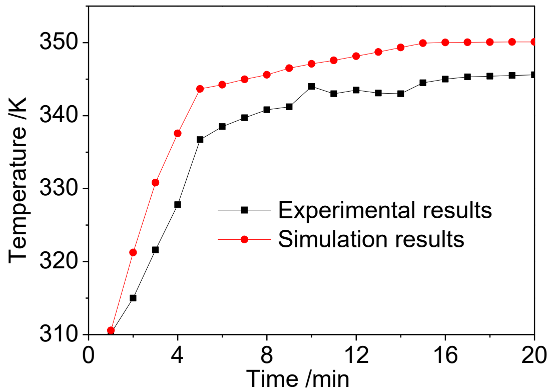

Figure 6: The comparison of CPU simulation and experiment.

The simulated results show good consistency with experimental results, which proves that the used computational model is available and reasonable.

4. Analysis and discussion

4.1 Analysis of the flow distributions

Considering the chassis of the special-purpose computer is almost fully closed with a fan on its upper side, the cooling is mainly based on conduction and convection in this paper. The convective coefficient is appropriately increased to include the effect of radiation. The flow distributions are obtained after iterations of 500.

Figure 7 shows that the convective air in the case goes through the large panel and flows into the corrugated plate duct between the guide plate and the large panel. Finally, the air flow runs out of the socket plate and passes by the fan located in the rear panel component. Figure 8 shows the flow distributions on the motherboard, the interface board and the power supply in the chassis. Because the inside of the chassis is enclosed, the airflow circulates between the internal components.

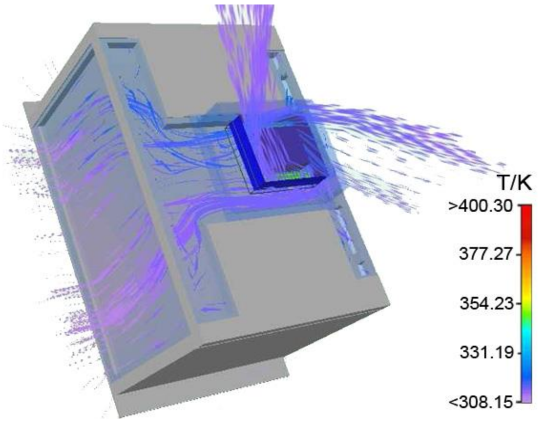

Figure 7: Board outside cover plate forced convection flow.

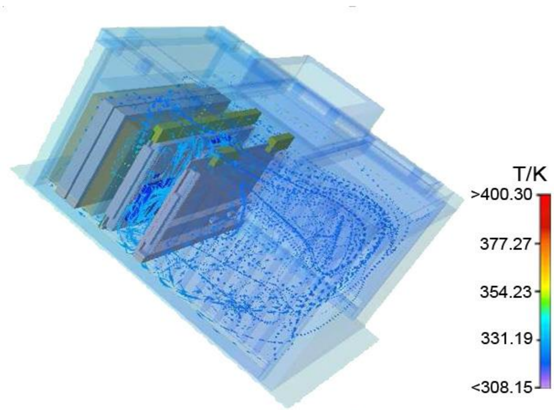

Figure 8: Box forced convection flow.

4.2 Analysis of temperature field

The temperature distribution inside the chassis and on the motherboard are shown in Figure 9 and Figure 10.

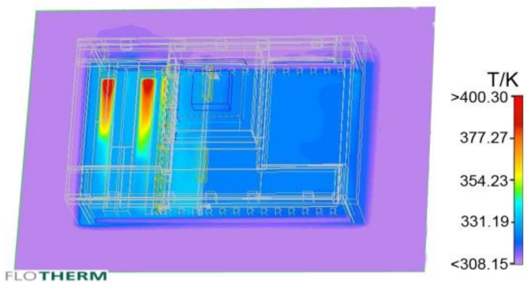

Figure 9: The temperature distribution of chassis.

It is observed that the highest temperature of the entire dedicated computer emerges at the upper power supply in Figure 9. Due to the effect of gravity, the temperature distribution is non-uniform, and the temperature difference is very large. The same heating power is found on the Chip1, the Chip2, the Chip3 and the Chip4 as shown in Figure 10. However, the temperature difference is great when the system cooling reach the steady state. The temperature of Chip4 is 340.35 K. With increasing the temperature values on the Chip3, the Chip2 and the Chip1, the temperature value of the Chip1 reached to 350.85 K. The Chip1 became the one which has the highest temperature on motherboard. The CPU obtains a maximal temperature value (350.25 K) compared to the other main components. It indicated that the performance and reliability will be reduced in a long-term high-temperature operation. Partial high temperature of the power supply will lower the performance and reliability of internal components, and structure aging and failure are accelerated by the high temperature distribution.

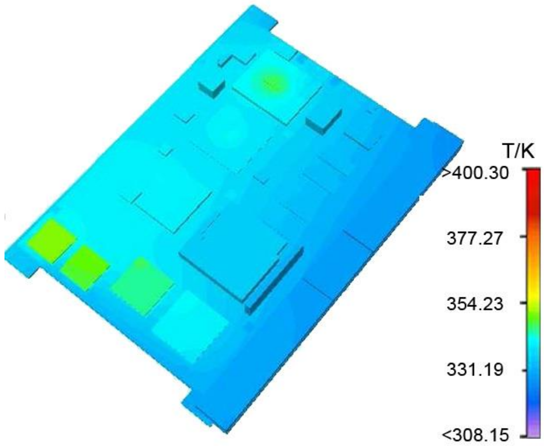

Figure 10: The temperature distribution of motherboard.

4.3 Optimization and improvement

As the main component of computer, PCB board is an important protection for the normal work. The intensity of the specific capacity will seriously affect the stability of the computer. In order to ensure the rapid and stable work, the thermal structure of PCB board must be adjusted to improve the cooling capacity. In general, the heat dissipation can be improved by enhancing the thermal conduction or increasing the area of heat dissipation. In this paper, increasing the heat dissipation area was used to improve the cooling performance.

The improved structure of motherboard cover is shown in Figure 11. Two small plates were added on the motherboard cover. Because the plates are connected with the surfaces of Chip1 and Chip2, more heat are transferred to the motherboard cover. The cooling area is increased, and the heat is taken away as soon as possible. Therefore, the temperature value of the Chip1, the Chip2, the Chip3 and the Chip4 would be reduced.

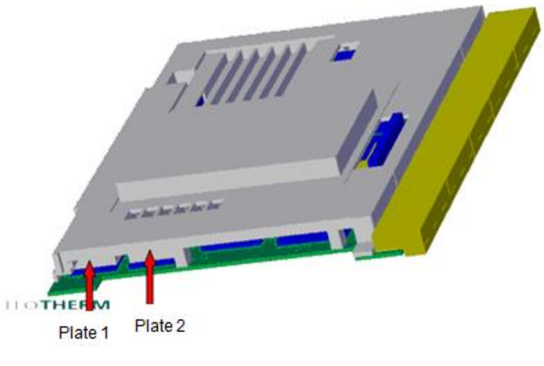

Figure 11: The improved structure of motherboard cover.

The temperature contours and values before and after improvement are shown in Figure 12 and Table 4. It is found that the temperature values of the Chip1 and Chip2 reduce by approximately 10 °C, and the working temperature for Chips 1-4 tends to be consistent. Therefore, the improvement of the structure is effective, and it extends the service life of the special-purpose computer.

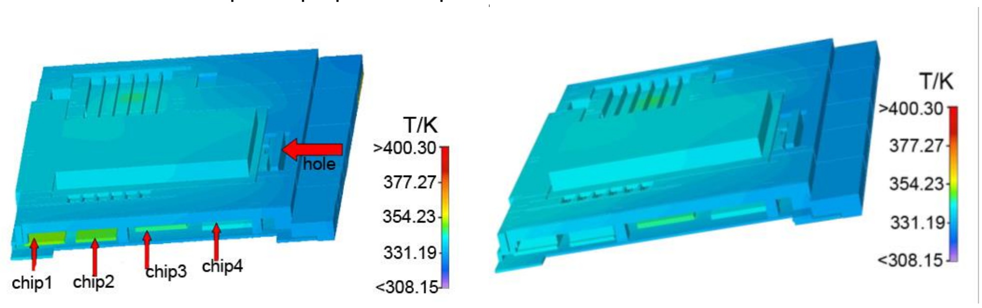

Figure 12: The temperature contours before (left) and after optimization (right).

Table 4: The temperature contrast of each element before and after the improvement of motherboard.

Elements	Temperature before improvement (K)	Temperature after improvement (K)
Chip1	350.85	340.95
Chip2	348.55	340.05
Chip3	344.95	345.25
Chip4	340.35	341.15

5. Conclusions

Numerical simulations for a special-purpose computer were investigated, and temperature distributions were studied by using the software Flotherm. The simulation results were compared with the experimental results, and the structure optimization was conducted. The main conclusions are summarized as follows:

(1) The simplified rules for the thermal analysis process are obtained, which simplifies the simulation model of the special-purpose computer reasonably. The simulation results are consistent with the experimental results.

(2) The temperature decreases and the heat dissipation is enhanced remarkably by adding two small plates to connect the Chips 1-2 to the motherboard cover. The plates provide a reliable path to take more heat away from the high temperature structure.

This paper provides theoretical and practical supports for further optimization of similar structures to improve the capacity of heat dissipation. It can be used in other relevant applications about structural simplifications.

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