Research on the Design and Analysis of Forced Air Cooling for Airborne Modular Integrated Rack

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Abstract. The avionics equipment encounters changeable and harsh thermal boundary conditions in its task profile, and its thermal performance directly affects electrical function, performance and reliability. The design flow of structure and heat dissipation for electronic equipment was proposed based on the engineering experience. An airborne modular integrated rack was taken as the research object to carry out the related research on design and analysis of forced air cooling. The structural configuration, heat dissipation scheme and thermal control measures of the airborne modular integrated rack were discussed, and the heat dissipation analysis was carried out. The results of simulation calculation and physical prototype test show that the thermal control design is reasonable and feasible. There will be certain reference and guiding significance to the design of similar electronic equipment.

Keywords: Integrated Rack; Forced Air Cooling; Thermal Design; Thermal Analysis

1 Introduction

With the booming development of avionics in recent years, especially the increasing degree of integration, avionics equipment shows a trend of high heat flux density. Avionics equipment faces variable and harsh thermal environments in its task profiles. Among the reasons for electronic equipment failures, 55% are due to poor heat dissipation [1-4]. When the operating temperature of the components exceed the allowable value, the components are likely to fail, which has a direct impact on the electrical function. Therefore, it is necessary to carry out the related research on thermal design and analysis for avionics equipment to ensure their excellent working performance and high reliability [5-6].

Most aircraft platforms are not able to provide special thermal control conditions such as liquid cooling system and environmental control air system [7-8]. The forced air cooling system design is required for most electronic equipment of large heat flux to ensure the requirements of the task are met.

The design flow of structure and heat dissipation for electronic equipment was proposed based on the engineering experience. According to the characteristics and performance requirements of a certain task, the thermal design and analysis of an airborne modular integrated rack were carried out. Based on the detailed introduction of the structural configuration, the thermal design scheme and the design work of structure and heat dissipation were carried out. The thermal simulation analysis of the equipment was carried out by using FloEFD software [9], and the prototype production was carried out based on the analysis results. The results of simulation calculation and prototype test showed that the thermal control design of the equipment is reasonable and feasible.

2 Design Flow of Structure and Heat Dissipation

The design of structure and heat dissipation should fully consider and evaluate the size, mass, thermal interface, environmental conditions, reliability, ergonomics and other multi-dimensional engineering factors of electronic equipment. Combined with engineering experience, the basic design flow of structure and heat dissipation for electronic equipment was proposed in this work, as shown in Fig.1.

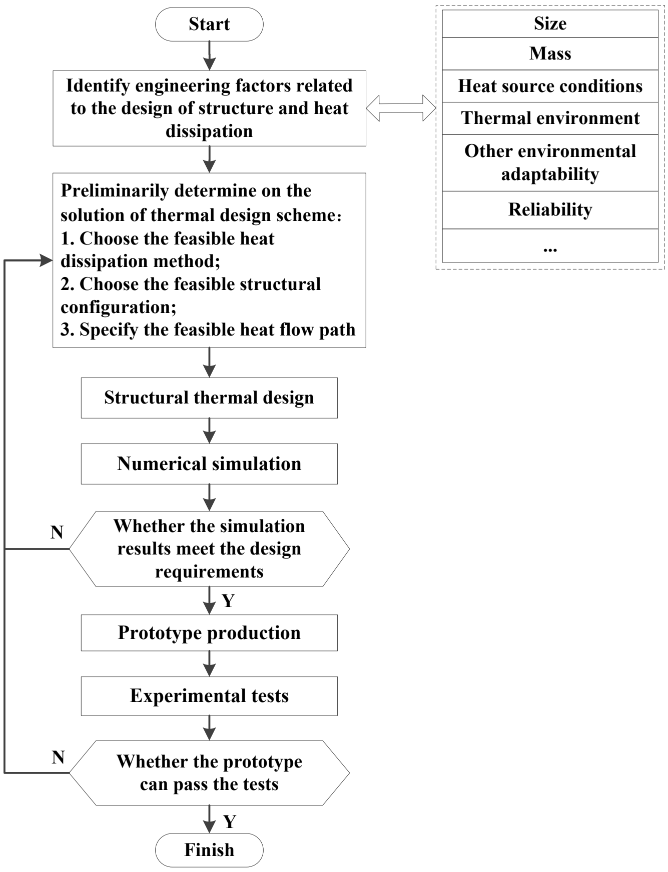


Fig. 1. Design flow of structure and heat dissipation for electronic equipment.

3 Structural Thermal Design

3.1 Structural Configuration

The structural configuration of avionics equipment mainly includes the integrated configuration and building block assembly configuration. The integrated configuration takes the line replaceable module (LRM) as the basic unit, which has high integration and good maintainability, is easy to expand and refit, and reduces the development and maintenance costs, but its size and mass are slightly insufficient compared with the building block assembly configuration.

In order to meet the maintenance needs of electronic equipment, while improving the reliability and fault tolerance of increasingly complex and highly integrated electronic systems, more and more avionics equipment adopts the design concept of integrated configuration based on LRM.

A modular integrated rack [10] consists of a rack body and a number of line replaceable functional modules. In general, the structural configuration of the integrated rack can be basically divided into three functional parts: the module installation area provides LRM installation space, mechanical interface and thermal interface; the electrical interconnection area is used to install PCB and provide electrical interconnection between the line replaceable modules; the external interface area is used for the installation of electric couplers and cables. The integrated rack has good maintenance and the LRM functional modules can be replaced quickly in daily maintenance.

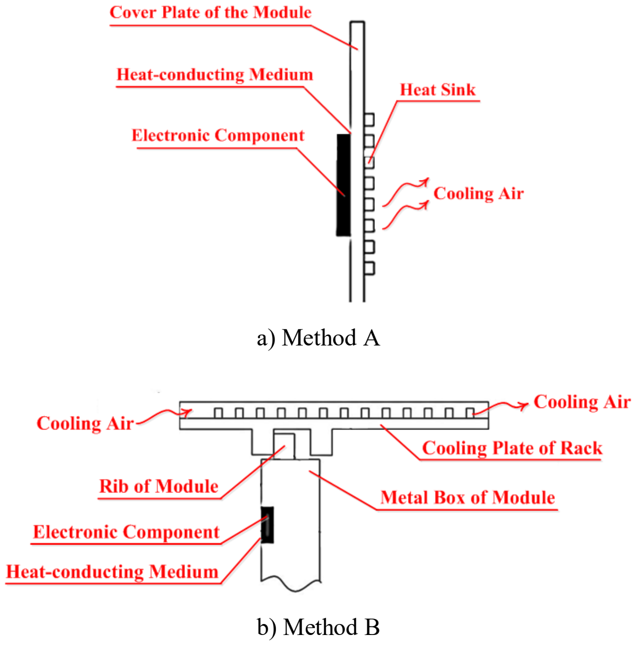


Fig. 2. Heat transfer path of forced air cooling methods.

3.2 Preliminary Heat Dissipation Scheme

The heat dissipation methods of avionics equipment are mainly divided into natural heat dissipation, forced air cooling, liquid cooling, etc. The natural cooling method mainly dissipates heat through conduction, natural convection and radiation, which has the advantages of reliability, safety and simple structure, but the heat dissipation efficiency is low, and it is only suitable for equipment with low heat. The design scheme of forced air cooling is to fix the heating device or module to the radiators, the heat is transferred to the radiators by conduction, and the cool air takes away the heat when it passes through the radiators. Liquid cooling has higher heat dissipation efficiency, the coolant flow channel is designed in the metal plate, and the heat of the equipment is taken away by the liquid coolant. Forced air cooling and liquid cooling have the advantages of high heat dissipation efficiency, but they need fans or liquid cooling system, and the structures are more complicated and the cost is higher.

According to the task requirements, the modular integrated rack contains a total of 18 electrical functional modules in 17 types. The heating power of the integrated rack is 725W. The maximum surface heat flux of a single module is 0.075W/cm^2, the natural cooling method cannot meet the needs of use. Considering that the aircraft platform cannot provide heat dissipation conditions such as environmental control air or liquid cooling system, it is proposed to use the forced air cooling method of simple structure and low cost.

According to whether the cooling air directly passes through the module, the commonly used forced air cooling methods can divided into the following two forms, the main difference is that the heat transfer path is different, as shown in Fig.2. In contrast, method A has lower thermal resistance than method B, relatively higher efficiency of heat transfer.

Table 1 is the summary of the heating power of modules.

Table 1. Summary of the Heating power of modules.

No.	Summary of Heating Power			
	Module name	Number of work modules	Heating power of a single module (W)	Subtotal of heating power (W)
1	Module 1	1	25	25
2	Module 2	1	20	20
3	Module 3	1	40	40
4	Module 4	1	40	40
5	Module 5	1	35	35
6	Module 6	1	65	65
7	Module 7	1	65	65
8	Module 8	1	36	36
9	Module 9	1	30	30
10	Module 10	2	32	64
11	Module 11	1	55	55

No.	Summary of Heating Power			
	Module name	Number of work modules	Heating power of a single module (W)	Subtotal of heating power (W)
12	Module 12	1	70	70
13	Module 13	1	30	30
14	Module 14	1	20	20
15	Module 15	1	25	25
16	Module 16	1	70	70
17	Module 17	1	35	35
Summary		18		725

In order to reduce the heat transfer interface, the heat dissipation scheme adopts the method A in Fig.2. Considering the large number of LRM modules in the rack and the relatively dispersed heat, axial flow fans are used for the heat dissipation of this modular integrated rack.

$$q_{\mathrm{m}} = \frac{Q}{C_p \cdot \rho \cdot \Delta_T} \quad (1)$$

Where, Q is total heating power, W; c_p is specific heat capacity at constant pressure, $\mathrm{J/(kg \cdot ℃)}$; ρ is air density, $\mathrm{kg/m^3}$; Δ_T is temperature difference between air inlet and outlet, ℃.

It is calculated that the required volume flow rate is approximately 519.4m³/h (305.5CFM). The volume flow rate at the operating point of the fan is usually 2/3 of its maximum volume flow rate, so the required maximum volume flow rate is estimated to be 779.1m³/h (458.3CFM). Comprehensive consideration of volume flow rate, installation space, mass, power, noise, cost and other factors, we choose 5 low-cost fan J85FZW511-38G-BC. By limiting the maximum speed to 8000r/min through PWM function, the peak power is reduced to 11.85W, the maximum volume flow rate is approximately 171.5 m³/h (100.9 CFM), the maximum static pressure is reduced to 29.62mmH_2O.

Fan curve chart is shown in Fig.3.

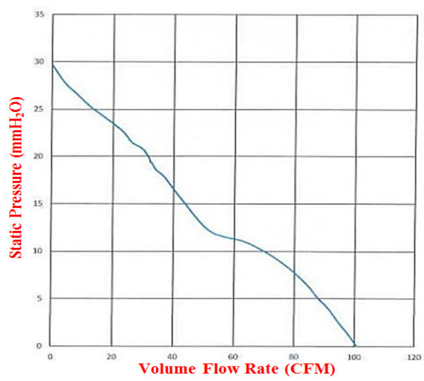


Fig. 3. Fan curve chart (limit the maximum speed to 8000r/min).

Through the speed limit, the maximum noise of 5 fans working at the same time is approximately 65.5dB.

Modular integrated rack is a very complex integrated equipment, it is difficult to get a reasonable thermal design scheme based on empirical formula. After determining the preliminary heat dissipation scheme according to the thermal design engineering experience, more detailed structural thermal design work should be carried out, and heat dissipation analysis and test verification should be carried out to obtain more reasonable heat dissipation design results.

3.3 Structure Design of Modular Integrated Rack

The modular integrated rack mainly consists of front panel, rear panel, upper side plate, lower side plate, left side plate, right side plate, supporting plate, frame, printed circuit board, fan assembly and vibration isolators, as shown in Fig.4.

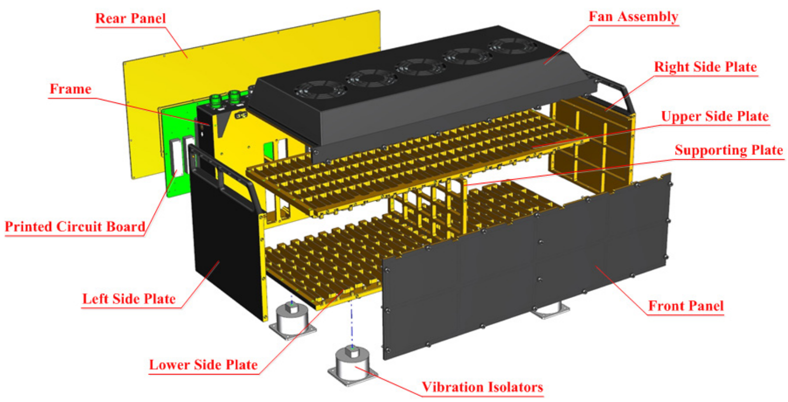


Fig. 4. Three dimensional diagram of the modular integrated rack.

The module installation area consists of upper side plate, lower side plate, support board, left side plate and right side plate, which provides the installation space for the functional modules, and provides the mechanical and environmental interfaces for insertion, extraction, locking and heat transfer. The frame supports the installation of printed-circuit board, electric couplers and cables. The fan assembly adopts the quick disassembling method, which is designed with the guided ribs on both sides to guide and position during quick assembly and disassembly. Handles are designed on both sides of the rack for carrying equipment. Between the modules, there is a space of 3mm-5mm to form heat dissipation channels.

3.4 Structure Design of LRM Module

The structure of the LRM electrical functional modules is shown in Fig.5, which consists of metal box, cover board, circuit board, insertion & extraction device, wedge-shaped locking mechanisms and electrical connector.

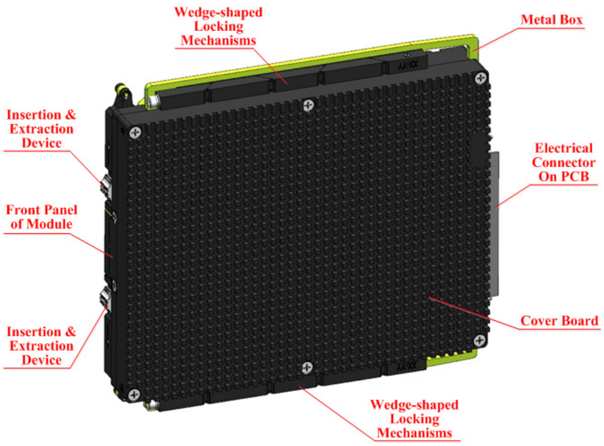


Fig. 5. LRM module structure

It can be seen from Fig.2 and Fig.5, the heat transfer of the module using method A is mainly carried out by convection through its two sides, and the conduction effect of the module rib is relatively weak. The main transfer path of the heat of chip: chip surface→ thermal interface material→ cover plate of the module and its heat sink→ cooling air. For chips with high heat flux, the corresponding heat sink should be designed.

4 Thermal Analysis

In order to check whether the thermal design measures are effective, a thermal simulation model was constructed with FloEFD, and steady-state thermal analysis of the rack was solved at ambient temperature of 70°C.

The simulation parameters are shown in Table 2.

Table 2. Simulation parameters.

No.	Simulation Parameters			
	Name	***Thermal conductivity (W/m/°C)***	***Emissivity***	***Contact thermal resistance (°C▪m²/W)***
1	Printed circuit board	(30, 30, 0.3)	0.6	/
2	Metal box of module (5xxx series aluminum alloy)	117	0.3(internal surface)/0.7 (outside surface)	/
3	Interface between modules and rack ribs	/	/	6×10^{-4}
4	Interface between other metal structures	/	/	1×10^{-3}

The steady-state thermal simulation results of the modular integrated rack were obtained. The temperature contour plot is shown in Fig.6 and Fig.7. The calculation results of flow field are shown as in Fig.8. The operating point of a fan is shown in Fig.9.

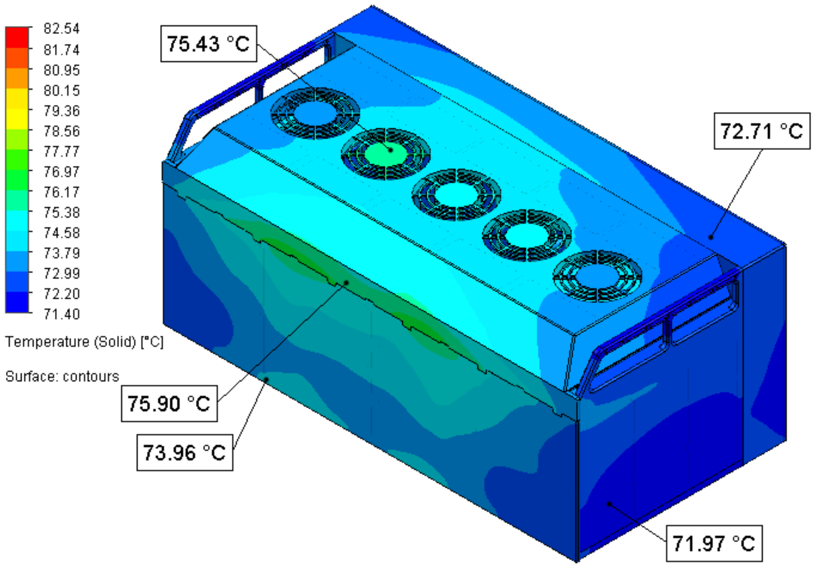


Fig. 6. Temperature contour plot of rack.

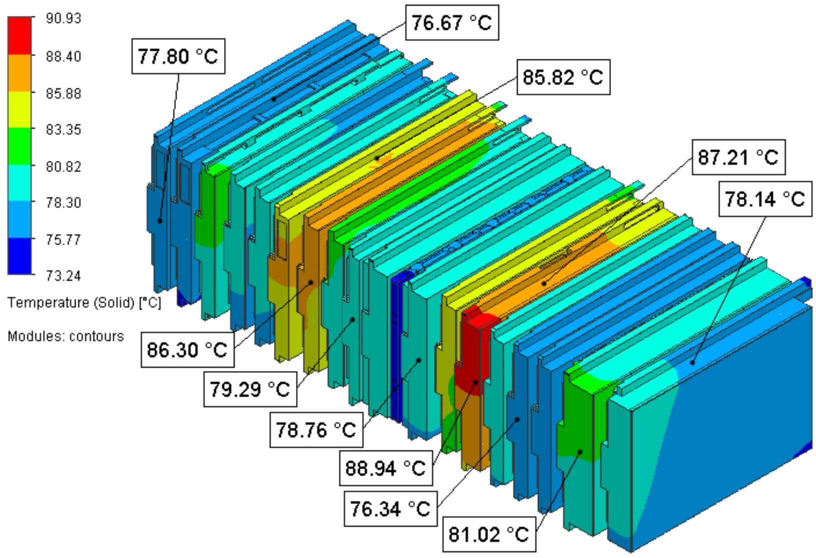
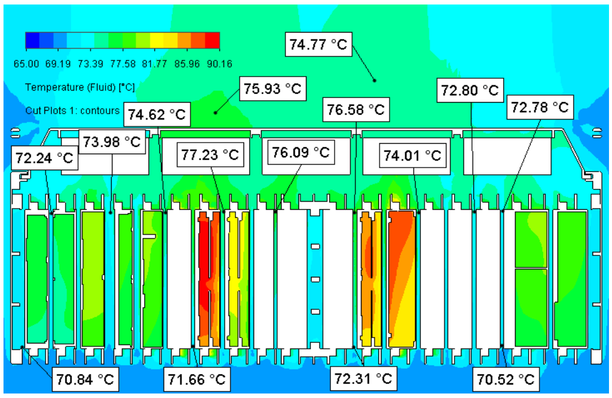
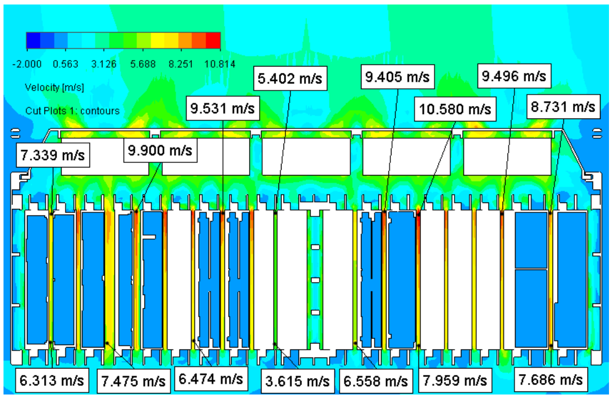


Fig. 7. Temperature contour plot of functional modules.



a) Temperature contour plot of flow field



b) Velocity contour plot of flow field

Fig. 8. Calculation results of flow field.

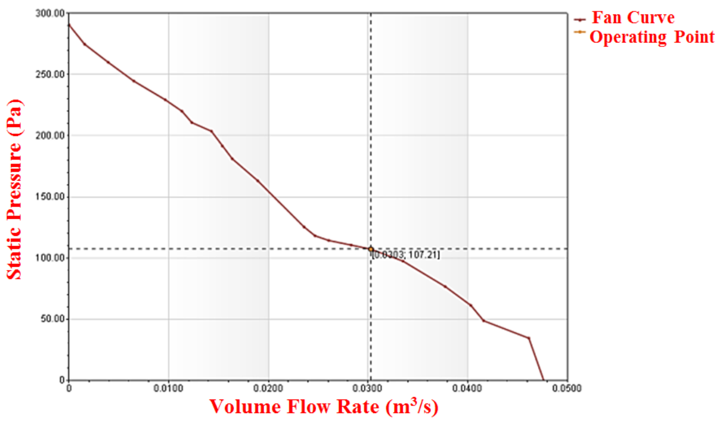


Fig. 9. Operating point of a fan.

It can be seen from the figures, the highest temperature of the outer surface of the integrated rack is 75.9℃; module 12 has the highest surface temperature, reaching 88.94℃; wind speed between modules is (3.6~10.6) m/s; the operating point of the fan is ideal; the volume flow rate of a single fan is about 0.0303 m^3/s(109.08 m^3/h). In conclusion, the airduct design of the rack is feasible and the selection of fans is reasonable.

On the premise of meet the requirements of mass and size, the heat sinks of high heating power module should be improved to increase the surface convective heat transfer coefficient. Taking the temperature and velocity of the cooling air on both sides of the module as the boundary thermal conditions, the simulation analysis of each module was carried out at the electronic component level.

The prototype production of the integrated rack was carried out, and the prototype passed the environmental test successfully, which verified the reasonability of the thermal design scheme.

5 Conclusions

The avionics equipment encounters changeable and harsh thermal environment in its task profile, so it is of great engineering significance to carry out thermal control design to guarantee the electrical function, performance and reliability of the products. The basic design flow of structure and heat dissipation for electronic equipment was proposed based on the engineering experience, and the related thermal design and analysis were carried out with an airborne modular integrated rack as the research object. Through structural configuration, heat dissipation scheme, selection of fans, airduct design, heat sink optimization and other design measures to meet the needs of use in thermal environment. The thermal performance of the integrated rack was analyzed by FloEFD software. The results of simulation calculation and prototype test show that the measures of forced air cooling are reasonable and effective, which will be certain reference and guiding significance to the design of similar electronic equipment.

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