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Cooling the driving system for high altitude aircrafts

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ABSTRACT

The high-altitude environment with a low atmospheric pressure and low air density would significantly affect the cooling performance, which can further affect the heat dissipation of driving system. This work studies the impacts of the high-altitude environment on cooling the driving system of high altitude aircrafts. A 3-D CFD model was developed. Based on simulations, the influences of the altitude, solar radiation and the heat load on the operating temperature of the driving system were analyzed. The cooling performances on the ground and at high altitudes were also compared. The results showed with the increase of altitude, the maximum temperature of driving system decreased firstly until 4km and then increased. And a large deviation (12°C) would occur if the solar radiation was not considered for high altitude aircrafts.

Keywords: driving system, finned radiator, high altitude, solar radiation, cooling

1. INTRODUCTION

The high-altitude aircraft is widely applied in communication and environmental monitoring with the advantage of fixed-point, long-term air-stationing and low energy consumption [1]. High-altitude extreme environment refers to the stratosphere adjacent to the space (usually ranges from 10km to 20km). And the environmental condition, such as the atmospheric pressure, air density and temperature, wind speed and direction and solar radiation, is significantly different to that on the ground [2]. Even though the air temperature is lower and the wind speed is higher, cooling the driving system is still a big challenge due to the much lower air density and stronger solar radiation. Air cooling is widely used due to the low cost and low weight [3]. Elsayed et al. [4] studied the thermal performance of a finned radiator with a deflector in a fan driving system in a high-altitude environment. Results showed that the optimal fin structure is different from the ground environment.

Even though some works have been done to study the impacts of the different conditions at high altitude on the cooling performance, there is still lack of a comprehensive investigation covering all of them. This work aims to study the performance of using a finned radiator to cool the driving system of high altitude aircrafts in high-altitude environment. A validated 3D model was established, and the influence of altitude, heat load and solar radiation on the cooling the driving system was studied by simulation.

2. SYSTEM DESCRIPTION AND CFD MODEL

2.1 Driving system

The driving system consists of the packing box, the control circuit board, the driving circuit board, and the power circuit board. Heat mainly comes from chips located on the power circuit board. Other heat, such as resistors and diodes, was ignored. A finned radiator was embedded under the bottom of the packing box, as shown in Fig. 1(a). It could effectively enhance the cooling of the driving system by improving the convective heat transfer coefficient (h) and heat dissipation area (A).

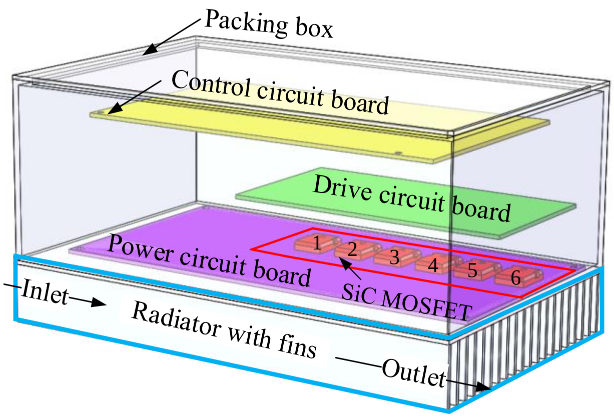


Fig 1 The structure of driving system and the finned radiator

When the system operates, the external environment varies with altitude, as shown in Table 1. The heat load and wind speed were set as 100W-400W and 10m/s, respectively [5]. For the driving system, it is required that the surface temperature of chips cannot exceed 150°C [6].

Table 1 The environmental characteristics at different altitudes [7]

Altitude (km)	Tamb (°C)	Air density (kg/m^3)	Air pressure (Pa)
0	15	1.225	101325
2	2	1.007	79500
4	-11	0.8194	61640
6	-24	0.6601	47180
8	-37	0.5258	36500
10	-50	0.4135	26440
12	-56.5	0.31083	19330
14	-56.5	0.22675	14100
16	-56.5	0.16542	10290
18	-56.5	0.12068	7500
20	-56.5	0.0889	5529

2.2 CFD model

A model was developed by using The Solidworks® and Ansys workbench® to simulate the temperature rise of the driving system in different altitude environments. The Continuity Equation, Momentum conservation equation, Energy conservation equation, and the radiation equation were expressed as follow (1)-(4).

Continuity Equation:

$$\frac{\partial\rho}{\partial t}+div\left(\rho\vec{u}\right)=0 \tag{1}$$

Momentum conservation equation:

$$\begin{aligned}
&\frac{\partial(\rho u)}{\partial t}+div(\rho u\vec{u})=div(\mu grad(u))-\frac{\partial p}{\partial x}+S_u\\
&\frac{\partial(\rho v)}{\partial t}+div(\rho v\vec{u})=div(\mu grad(v))-\frac{\partial p}{\partial y}+S_v\\
&\frac{\partial(\rho w)}{\partial t}+div\left(\rho w\vec{u}\right)=div\big(\mu grad(w)\big)-\frac{\partial p}{\partial z}+S_w
\end{aligned} \tag{2}$$

Energy conservation equation:

$$\frac{(\rho T)}{\partial t}+div(\rho\vec{u}T)=div(\frac{\lambda}{c_p}grad(T))+S_T \tag{3}$$

Radiation equation：

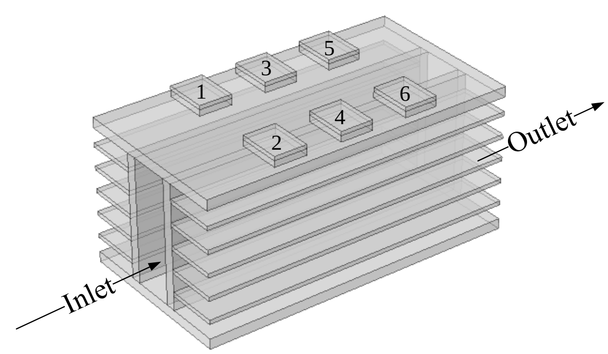
$$Q=\varepsilon\sigma(T_{amb}^4-T^4) \tag{4}$$

where, ρ, λ, c_p, and μ are density, thermal conductivity, heat capacity at constant pressure, and dynamic viscosity of air, respectively; S_u, S_v, and S_w are source terms in the directions of *u*, *v*, *w*, respectively; S_T is the source term in energy conservation equation; T_{amb} is the ambient temperature; *T* is the temperature of driving system; ε is emissivity; and σ is Stefan-Boltzmann constant.

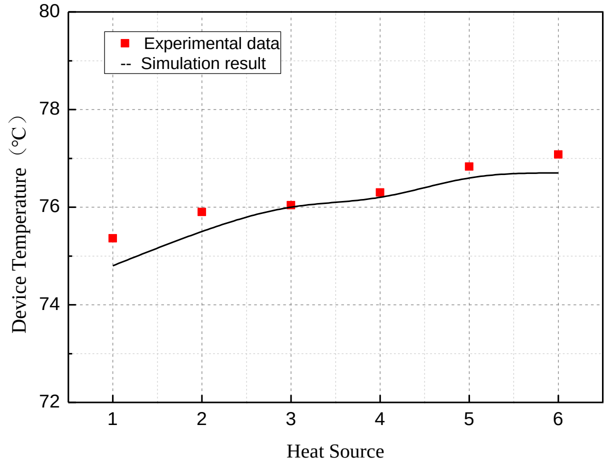
2.3 Model validation

The CFD model was validated against the experiment data from [8]. The heat released from an inverter was dissipated by using a finned radiator, as shown in Fig 2(a). Same inputs were used in the simulation as the literature: the ambient temperature and the volume flow rate of air were 15°C and 60m^3/h, respectively. The thermal conductivity of the radiator and the effective heat dissipation area were 201 W/m·K and 1770cm^2, respectively. And the total heat load was 180W (30W for each).

Fig 2(b) compared the simulated results and the measured data. A good agreement can be observed. The largest temperature difference (0.9°C) occurred at chip # 1 and 2.



(a) The structure of inverter and the finned radiator in ref. [8]



(b) The validation between the experimental data and the simulation results

Fig 2 Validation between experiment and the simulation

3. RESULT AND DISCUSS

In order to study the cooling of the driving system for high altitude aircrafts, the maximum temperature on the chips was employed as the key performance indicator.

3.1 Impacts of altitudes

Fig 3 shows the effect of altitude on the maximum temperature of the driving system. At different altitudes, the air temperature and the air density clearly changed and therefore, influence the cooling performance. With the increase of altitude, the maximum temperature decreases firstly and then increases. For the decrease of the maximum temperature, the decrease of air temperature is the main reason; while for the increase of the maximum temperature, it is mainly due to the decrease of the air density.

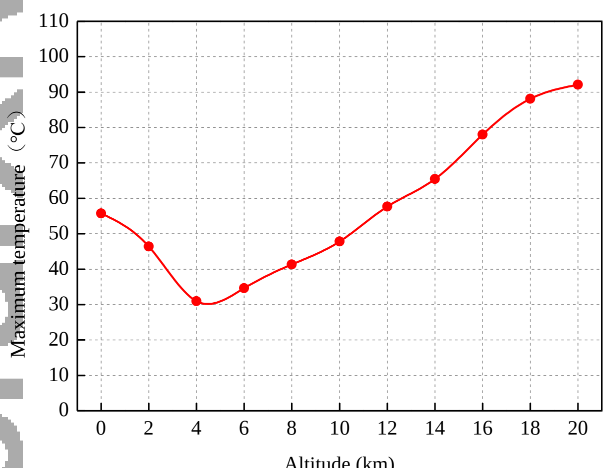


Fig 3 Maximum chip temperature of driving system at different altitudes

3.2 Effects of heat loads

The effect of heat loads is illustrated in Fig 4. The maximum temperatures for a high altitude of 10km is compared with those on the ground (0km).

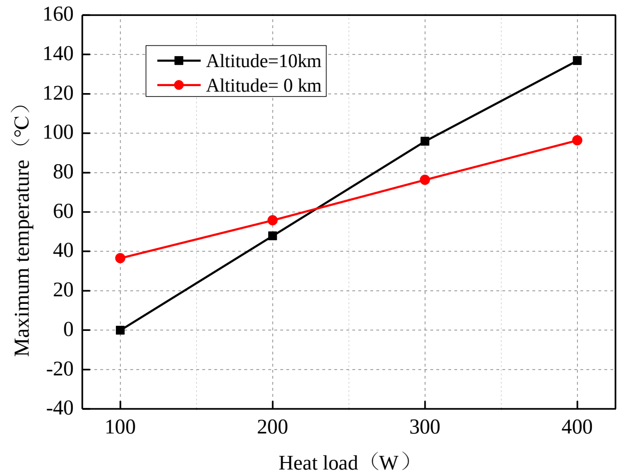


Fig 4 The relationship between maximum chip temperature and heat load of driving system at different altitudes

It is apparent that the maximum temperature increased linearly with the increase of the heat load. However, the effect of heat loads is more obvious at high altitude. For example, when the heat load is increased from 100 to 400 W, the maximum temperature increases from 0 to 136.9°C at a high altitude, but only from 36.5 to 96.4°C on the ground.

3.3 Effects of solar radiation

The effect of solar radiation on the cooling the driving system can be found in Fig. 5. The solar radiation can significantly affect the maximum temperature at high altitude. It was ignored in some studies. According our simulation, a large deviation (12°C) would occur if the solar radiation was not considered in cooling the driving system for high altitude aircrafts.

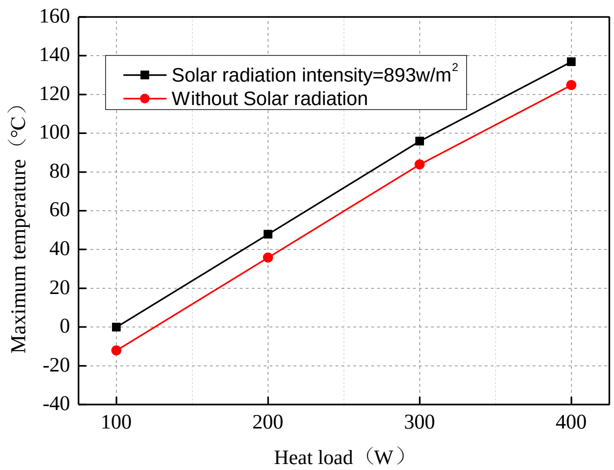


Fig 5 The effect of different direct solar radiation intensity

4. CONCLUSION

A 3-D CFD model was developed in this work to study the impacts of the high altitudes on cooling the driving system of high altitude aircrafts. Based on simulations, it can be concluded that:

1. The maximum temperature of driving system is affected by the air temperature and air density, which decreases firstly until 4km and then increases with the increase of the altitude.
2. The change of heat load has more obvious impacts on the maximum temperature at high altitude than on the ground.
3. Neglecting solar radiation can lead to a big deviation when assessing the performance of cooling the driving system for high altitude aircrafts.

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REFERENCE

[1] Luo L, et al. Analysis of Propeller Driving Motor for High Altitude Airship. [J]. Acta Astronautica. 2009, 30(6):2140-2144.

[2] Simpson J E. A comparison between laboratory and atmospheric density currents[J]. The Quarterly Journal of the Royal Meteorological Society, 1969, 95(406):758-765.

[3] Mohamed M M. Air cooling characteristics of a uniform square modules array for electronic device heat sink[J]. Applied Thermal Engineering, 2006, 26(5-6):486-493.

[4] Elsayed M L, Mesalhy O, Kizito J P, et al. Performance of a guided plate heat sink at high altitude[J]. International Journal of Heat and Mass Transfer, 2020, 147(Feb.):118926.1-118926.15.

[5] Boteler L, Urciuoli D, Ovrebo G, et al. Thermal performance of a dual 1.2 kV, 400 a silicon-carbide MOSFET power module[J]. Annual IEEE Semiconductor Thermal Measurement & Management Symposium, 2010, 51(2):170-175.

[6] Gould K , Cai S Q , Neft C , et al. Liquid Jet Impingement Cooling of a Silicon Carbide Power Conversion Module for Vehicle Applications[J]. Power Electronics IEEE Transactions on, 2015, 30(6):2975-2984.

[7] https://www.engineeringtoolbox.com/international-standard-atmosphere-d_985.html

[8] Su Hang, Jiang Yan, et al. Design of 7.5 kW SiC Inverter for Electric Vehicles[J]. Journal of Power Supply, 2019, 017(003):126-132.