Research on the cooling method of the payload ground test for a communication satellite

Yougao Fan¹², Tao Guo¹², Shuai Chen¹, Peng Zheng¹, and Jie Zhang¹²
¹Beijing Institute of Spacecraft Environment Engineering, Beijing 100094, China
²Beijing Engineering Research Center of the Intelligent Assembly Technology and Equipment for Aerospace Product, Beijing 100094, China

Corresponding author E-mail: fanygao@163.com

Abstract. In view of the problem of the excessive heat consumption in the process of ground test of a communication satellite, a cooling system solution is set up by using industrial air conditioner for cooling the satellite payload, and the thermal simulation analysis of the test conditions for the satellite. Through the thermal simulation analysis, the air supply mode of the cooling system, the technical parameters of the cold air blower, and the appropriate air supply temperature, wind speed, air volume and other parameters are given to ensure the normal working temperature level of the equipment during the ground test of the satellite payload.

1. Introduction

The operations for assembly, integration, and testing (AIT) are very important factors in research into satellites [1, 2]. In order to ensure the smooth progress of the test work, ground equipment systems must be built completely, then the performance and functionality of the satellite must be done for the full test [3].

When a communication satellite is tested, the heat consumption of the load module is up to 6000W. In the ground test, it is necessary to use the air cooler, fan and other means to dissipate heat in order to ensure the normal working temperature level of the load module and the antenna module [4]. In view of the above requirements, we are going to develop cold air cooling equipment. However, because of the inability to determine the air supply parameters to meet the cooling requirements under various conditions, thermal simulation analysis is needed before the cooling equipment is developed [5, 6]. Through the simulation results, the parameters of the cooling system, such as the air supply mode of the cooling device, the technical parameters of the cooling fan, and the appropriate parameters such as the air supply temperature, wind speed and air volume in each operating condition are given.

2. A survey of the satellite

The main structure of the satellite has inherited the idea of the setup of the modular structure of the DFH-4 platform, and has been improved adaptively according to the specific load distribution, which can be divided into the propulsion module, the service module and the load module [7, 8]. The load module is composed of the board over the earth, the north board and south board of the payload module, and the north clapboard and south clapboard.

The south board of the load module mainly includes 24 solid state power amplifiers (SSPA) and the equipment of the measurement and control subsystem. The north board of the load module mainly includes 20 SSPAs and the equipment of the digital transmission subsystem.
The heat consumption of the payload cabin mainly comes from SSPA. The normal working temperature range of SSPA is -15℃ to 50℃. The heat rate value of the south board is 3300W, and the south board is 2700W.

The south board of the load module, the south partition board, the north board and the north baffle are aluminum honeycomb boards which are made up of aluminum surface board and aluminum honeycomb core (the transverse thermal conductivity is 2.8 $W/m\cdot K$, and the longitudinal thermal conductivity is 1.5 $W/m\cdot K$). The remaining deck panels are carbon fiber honeycomb panels made of carbon fiber covered aluminum honeycomb cores (transverse thermal conductivity of 1.1 $W/m\cdot K$, and longitudinal thermal conductivity of 1.5 $W/m\cdot K$).

3. Ground test condition analysis

3.1. Operating condition 1: Load module single test

Load module single condition contain the board over the earth, south board of the load module, north board of the load module. The load module is parked on the turning rack through the cage, the vertical state (+Z axis of the satellite mechanical coordinate system) or the horizontal state (+X or the -X axis of the satellite in the mechanical reference coordinate system). The external surface of the south or north board of the load module also can be ventilated and dissipated. Operating condition 1 is shown in Figure 1.

Under this condition, the east and west sides of the load module are opened. The industrial air conditioners are arranged on both sides of the load compartment, and the cold wind is transported to the heat load area of the module.

![Figure 1. Load module single test condition](image)

3.2. Operating condition 2: Whole satellite test (east and west board opened)

Whole satellite test contain load module and platform, that is, all the boards are installed exclude the east and west board. Vertical state (the +Z axis of satellite in the mechanical reference coordinate system is upturned), the satellite is parked on a two axis turntable or a whole satellite rack. When the south board and the north board maintain bare surfaces, the inner and outer surfaces of the south board and the north board can be ventilated and heat dissipated. Operating condition 2 is shown in Figure 2.

Under this condition, the east and west boards of the satellite are opened, and the industrial air conditioners are arranged on the east and west sides of the satellite to transmit cold air to the heat consumption area of the load module. The cold air pipe needs to reach 2000mm to 5000mm from the ground, it is necessary to design and process cold air pipe auxiliary fixtures.

3.3. Operating condition 3: Whole satellite test (east and west board closed)

During the operating condition 3, all the boards of the satellite are installed, as shown in figure 2.

The satellite attitude is as follows.

a. Vertical state, the +Z axis of satellite in the mechanical reference coordinate system is upturned.

b. Level state, the +Y or -Y axis of the satellite is upturned.
c. Tilted state, the +Z axis of the satellite in the mechanical reference coordinate system is 45 degrees to the horizontal line.

When the south board and the north board maintain bare surfaces, the inner and outer surfaces of the south board and the north board can be ventilated and heat dissipated. In this state, the east and the west board of the satellite is closed, and the industrial air conditioners are arranged on the west side of the satellite. The cold wind is transported to the heat consumption area in the load module through the opening of the western upper board.

(a) east and west board opened         (b) east and west board closed

Figure 2. Whole satellite test condition

4. Overall cooling design scheme

Through investigations and researches, it is proposed to use the mobile industrial air conditioners as the cooling air to provide the main engine. The cold wind passes through the east and west sides of the load module (operating condition 1) by the cold wind pipes, the east and the west sides of the satellite (operating condition 2), and the openings of the whole satellite (operating condition 3) to the main heat rate equipment area. The main parameters of the mobile industrial air conditioner are as shown in Table 1.

| Technical name       | Technical parameter                        |
|----------------------|--------------------------------------------|
| Overall dimensions   | 560mm × 630mm × 1260mm                     |
| The power supply     | 220V/50Hz                                  |
| Refrigerating capacity | 6500W                                    |
| The cold wind quantity | 910m³/h                                |
| Consumed power       | 2.4kW                                     |

The schematic diagram of cooling system suitable for operating condition 1 and operating condition 2 is shown in Figure 3. As the height of the air conditioning pipe outlet is more than 1300mm, while the operating condition 1 need to reach a maximum distance of 3800mm from the cold wind to the ground level, and the operating condition 2 needs to pass the cold wind to the highest distance to the ground 5300mm, so it is necessary to design cold air pipe auxiliary fixtures.

Figure 3. Diagram of overall cooling design scheme for operating condition 1 and 2
The schematic diagram of cooling system suitable for operating condition 3 is shown in Figure 4. Because the height of the air conditioning duct outlet exceeds 1300mm, a cold air pipe auxiliary fixture must be designed. In addition, as the operating condition 3 can only enter the heat consumption area of the load module through the cold wind of the west upper board, it is necessary to assist the cooling air to assist the cold wind on the surface of the north and south board of the load module.

![Figure 4. Diagram of overall cooling design scheme for operating condition 3](image)

5. Thermal simulation analysis

5.1. Parameters setting

The fluid is the air, considering the influence of temperature changes on the gas density, the ideal gas model is selected, and the other parameters remain the default values, as shown in Table 2.

| Parameter                  | Variable | Value | Unit     |
|----------------------------|----------|-------|----------|
| Density                    | \( \rho_g \) | \( \rho_g = (P_{op} + P)/(T_g R/M_w) \) | kg/m³   |
| Specific heat capacity     | \( c_{p,g} \) | 1006.43 | J/kg·K   |
| Heat conductivity coefficient | \( \kappa_g \) | 0.0242 | W/m·K    |
| Molecular viscosity        | \( \mu_g \) | 1.8×10⁸ | kg/m·s   |
| Thermal diffusion coefficient | \( \beta \) | 0.00333 | 1/K     |
| Molecular weight           | \( M_w \) | 28.966 | kg/k·mol |
| Perfect gas constant       | \( R \) | 8.3145 | J/mol·K  |
| Operating pressure         | \( P_{op} \) | 101325 | Pa       |

5.2. Simulation results of the operating condition 1

First of all, through preliminary simulation, it is preliminarily determined that when the number of the air conditioners is four to six, it may meet the heat dissipation requirements. On this basis, a variety of combination analysis is made for the specific layout of the air conditioners at four to six. The simulation results are shown in Figure 5.

The simulation results show that, when the number of air conditioners is four, it is possible to meet the heat dissipation requirement from the angle of the total input cooling volume, but it is difficult to find a specific arrangement to meet the heat dissipation requirements due to the limitation of the number of air outlets and the uneven distribution of the heat dissipation element. When the number of air conditioners is five, the overall temperature of the cooling components decreases, but it still does not meet the requirements. When the number of air conditioners is six, the demand for cooling conditions is determined by optimizing the outlet layout. The vent outlet which is affected by the position of the cage is adjusted, and the vent outlet which is indirectly influenced by the adjustment of
the outlet position is adjusted. After several simulation attempts, the outlet layout of the vent is obtained.

Figure 5. The simulation results of operating condition 1

(a) four air conditioners                    (b) five air conditioners                  (c) six air conditioners

5.3. Simulation results of the operating condition 2

On the basis of the simulation results of the operating condition 1, six air conditioners are considered for operating condition 2. The position and orientation of the outlet of six air conditioners are adjusted in order to get reasonable outlet layout. Through simulation, it is found that the Butler cabin in the middle can satisfy the heat dissipation demands even if there is no air outlet and cooling air. Operating condition 2 increases the middle bearing tube and other deck, which is more closed than the condition 1, which is beneficial to the cooling of the air conditioner to reduce the temperature of the radiator components. But on the other hand, the increase of the deck has limited the space layout of the outlet, and reduces the influence area directly acting on the heat dissipation element by the outlet. After the simulation adjustment, the layout of outlet to meet the heat dissipation requirements is obtained. The simulation results are shown in Figure 6.

Figure 6. The simulation results of operating condition 2

5.4. Simulation results of the operating condition 3

Unlike the previous two operating conditions, there are only four round holes on the west side can be placed out of the vent, and due to the limitation of the internal components, the angle adjustment of the outlet is limited, thus limiting the placement of the vent and the angle of the air outlet. On the other hand, the more closed space makes the quantity of the cold air input relatively better kept inside, thus more beneficial for reducing the temperature of the cooling element. In the layout of the outlet, the upper two holes are close to the Butler matrix, so it is suitable for blowing the cold wind on the round holes to keep less loss of the cooling capacity and kinetic energy, and the outlet of the two holes at the bottom can be slightly inclined upward. So that the movement of the cold air to the upper part of the tight area is favourable.

It can be seen from Figure 7 that if only the air vent is arranged at the four circular holes and the air outlet is out of the air, the heat dissipation element in the bottom area can be blown by the cold air,
and the heat dissipation element in the middle and upper part is not directly affected by the cold wind, so the temperature is higher.

![Figure 7. The simulation results of operating condition 3](image)

6. Conclusion

In this paper, aiming at the problem of excessive heat consumption in the ground test of a communication satellite, a cooling system is set up by using industrial air conditioners to reduce the effective cooling of the satellite payload. Through the thermal simulation analysis of the ground test conditions, the air supply mode of the cooling system, the technical parameters of the cold blower, so does the appropriate air supply temperature, wind speed, air volume and other parameters are given to ensure the normal working temperature level of the equipment.

References

[1] Silva A. C. and Loureiro G. Quality assurance of complex systems - satellite AIT[C]. IEEE International Conference on Industrial Engineering and Engineering Management, 2009, 935-939.

[2] Kim J. H. and Kim B. Study on the reduction method of the satellite thermal mathematical model[J]. Advances in Engineering Software, 2017, 108: 37-47.

[3] Wang Y., Peng C., and Zhang W. Thermal analysis of multifunctional structural battery for satellite applications[J]. Applied Thermal Engineering, 2015, 78: 209-216.

[4] Yong Liu Y., Liu K.-P., Li Y.-L., Pan Q., and Zhang Q. A ground testing system for magnetic-only ADCS of nano-satellites[C]. IEEE Chinese Guidance, Navigation and Control Conference (CGNCC), 2016, 1644-1647.

[5] Qin J. Y., Wang J., Liu C., and Fu X. Y. Force-thermal coupling analysis of the docking basket for satellite thermal test[C]. 2017 8th International Conference on Mechanical and Aerospace Engineering, 2017, 326-329.

[6] Mascarenas D., Macknelly D., Mullins J., Wiest H., and Park G. Dynamic characterization of satellite assembly for responsive space applications[J]. Measurement Science and Technology, 2013, 24(7): 075101.

[7] Guo T., Hu R., Xiao Z., Zhao J., and Fang Z. Research to Assembly Scheme for Satellite Deck Based on Robot Flexibility Control Principle[C]. IOP Conference Series: Materials Science and Engineering, 2018, 324: 012086.

[8] Moore B., J Zan J., Hannah B., Chui T., Penanen K., and Weilert M. Mid Infrared Instrument cooler subsystem test facility overview[C]. IOP Conference Series: Materials Science and Engineering, 2017, 278: 012006.