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Dynamic temperature prediction of electronic equipment under high altitude long endurance conditions

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Abstract Unmanned Aerial Vehicle (UAV) is developing towards the direction of High Altitude Long Endurance (HALE). This will have an important influence on the stability of its airborne electronic equipment using passive thermal management. In this paper, a multi-node transient thermal model for airborne electronic equipment is set up based on the thermal network method to predict their dynamic temperature responses under high altitude and long flight time conditions. Some relevant factors are considered into this temperature prediction model including flight environment, radiation, convection, heat conduction, etc. An experimental chamber simulating a high altitude flight environment was set up to survey the dynamic thermal responses of airborne electronic equipment in a UAV. According to the experimental measurement results, the multi-node transient thermal model is verified without consideration of the effects of flight speed. Then, a modified way about outside flight speed is added into the model to improve the temperature prediction performance. Finally, the corresponding simulation code is developed based on the proposed model. It can realize the dynamic temperature prediction of airborne electronic equipment under HALE conditions.

1. Introduction

Unmanned Aerial Vehicles (UAVs) mostly fly at low altitude for a short endurance, and thus their surveillance area is small. These UAVs cannot meet the needs of future war, so many countries are developing the High Altitude Long Endurance (HALE) UAVs.[1] HALE UAV is a kind of airborne vehicle flying at high altitude, and can fight for considerable long period without recourse to land.[2] Its power may be provided by the

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solar and hydrogen energy.[3–5] However, HALE UAV will face a very harsh environment when it cruises at high altitude. According to the International Standard Atmosphere (ISA) 1976, the atmospheric temperature and density are about –55 °C and 0.1 kg/m^3, respectively, at the altitude of 10 –20 km. This harsh environment coupled with the high flight speed will make the heat transfer process become relatively complex. This will adversely affect the temperature control of electronic equipment.

The strong effect of outside convection heat transfer will lead to a much lower temperature of airborne electronic equipment. Conversely, if the heat generated by the equipment cannot be dissipated effectively in the long flight process, the local temperature of equipment will be much higher. Both of these conditions can cause unstable work performance of electrical equipment. Therefore, it is of great significance to predict a node temperature of equipment and then to improve the thermal control according to the prediction results.[6,7]

Usually, passive thermal management has a significant impact on the thermal balance of UAV during a long flight process.[8–10] In this paper, a thermal network analysis method will be developed for the HALE UAVs. The atmospheric environment model, the transient thermal model and the convective radiation model will be established.[11] The temperature simulation results of air and airborne electronic equipment are compared with the experimental results to verify the established model.[12–14]

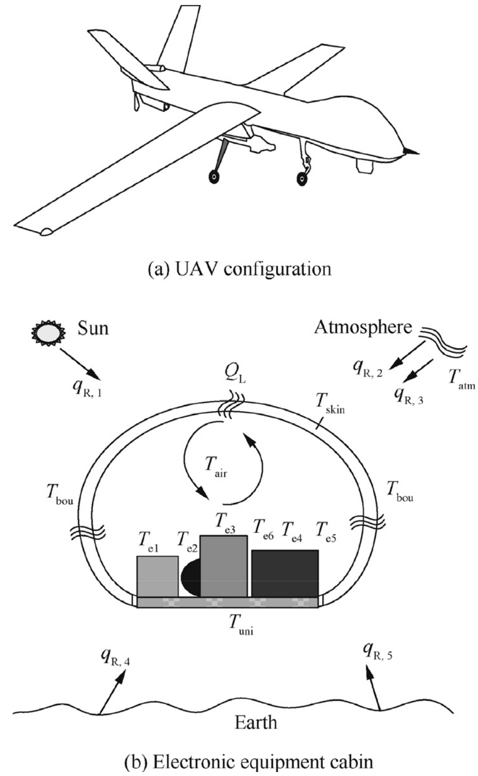

Fig. 1 Flight environment for UAV at a high altitude.

2. Computation scheme

2.1. Thermal environment analysis for UAV

The flight altitude and flight time of an HALE UAV will reach to 20000 m and 12 h, respectively. This will be a challenge for its thermal control performance especially when the HALE UAV uses passive thermal control technology. It needs to analyze its thermal environment and heat transfer process carefully.

Fig. 1 shows a typical flight thermal environment of UAV in a high altitude condition. This UAV uses passive thermal control technology based on a heat-pipe cold plate to maintain its temperature level of electronic equipment. The electric devices will transfer the heat to the passive thermal control device, the cabin walls and the cabin air. Outside factors, such as sun, atmosphere and earth, generate heat effects through the cabin walls.

In Fig. 1, there are six electrical devices in the cabin and they are installed on a cold plate where heat pipes are buried in advance. Six electric devices are installed on the cold plate in the UAV cabin, but only four devices are measured because there are two same groups of devices. The other two same devices will be considered in our thermal network model. But the temperature curves of four devices will be given in the following analysis. The internal heat transfer relationships include the convection between air and surface walls, the radiation and the heat conduction between the devices and the heat-pipe cold plate[10]. In addition, air leakage is also a non-ignorable factor for the heat transfer due to its non-sealed surface design. The external thermal effects include: (A) the direct solar radiation; (B) the forced convection, the infrared radiation and the diffuse radiation of atmosphere; (C) the reflected solar radiation and infrared radiation of earth.

In Fig. 1, $T_{e,i}$ represents the temperature of equipment node, i = 1,2,…,6. T_{air} and T_{uni} are the temperatures of the cabin air and the cold plate, respectively. T_{skin}, T_{bou} and T_{atm} are the temperatures of the vehicle skin, vehicle boundary layer and the outside environment, respectively. $Q_{R,i}$, i = 1,2,…,5, represent the radiation heat flux from the direct solar radiation, the infrared radiation and the diffuse radiation of atmosphere, the reflected solar radiation and the infrared radiation of earth. R is the thermal resistance, and its subscripts represent the thermal resistance relationship between two temperature nodes.

For a high altitude UAV, the above external and internal thermal effects will affect the temperatures of electronic devices together.[15] The studied UAV adopts the passive thermal technology to control its internal thermal environment and meet the specified requirements. Therefore, it is necessary to evaluate its temperature change range when the high altitude UAV is in a state of long flight time.[16]

Fig. 2 shows the heat transfer network of UAV. In this study, the lumped parameter method is used, that is, a temperature node can represent its average temperature.[17] All of the surfaces are diffuse gray surfaces. There is not heat conduction between the equipment and the cabin wall. The devices only have a heat conduction relationship with the cold plate and have a convection relationship with the cabin air. The remaining internal surface of cold plate is so small that its internal radiation can be ignored. The cold plate can transfer the heat to the outside environment by convection and radiation.

The radiation resistance between the devices is not marked in the figure because of the crowded icons, but the way of their