Study on the Fast Air Heating Method for the Testbed of the Environmental Control System of the Aircraft

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Abstract. In this paper, the necessity of studying the dynamic performance of the control system was firstly discussed. Through analysing the technical difficulties of the dynamic performance of the thermodynamic testbed, it was found that the most important problem to be solved was to simulate the actual working process of the engine and guarantee the test piece has a sufficiently high supply air temperature to meet the requirements of rapid air temperature rise. Through investigating the method of fast heating, the hot and cold blending method was proposed to realize the rapid response of the temperature. Through the switching of different air supply lines, the process of rapid temperature rising can be achieved.

1. Introduction

With the rapid development of civil aviation, the overall design requirements of large-scale delivery, long range and low fuel consumption have led to the continuous improvement of the performance of aircraft engines. As a result, the range of air temperature for the air-control systems has increased. Advanced Communications, navigation systems and ever-increasing on-board electronics make the heating power on the machine ever-increasing, resulting in increased air flow to the environment control system (ECS). So far much work has been carried out on the ECS. Vargas proposed a method to the thermodynamic optimization of components [1]. Ordonez and Bejan [2] took into account two basic questions in the thermodynamic optimization and analysed the robustness of the optimized models. In addition, the greatly varying ambient conditions undoubtedly change the ram air temperature parameters. As a result, the dynamic performance of the control system is facing a huge challenge [3][4].

Research on the dynamic performance of a control system requires a large number of ground-based laboratory tests to verify. Only in this way can we ensure that the problem is not brought to sky as much as possible. As the core of the environmental control laboratory, the thermodynamic testbed is a universal test platform for performance testing of the aircraft environmental control system. At present, the thermodynamic testbed mainly tests the principle verification and the static performance index, rarely involving the dynamic performance. A dynamic response simulation was performed by Eichler [5], which was to study sensitivity, identify possible problem areas in the design, and act as a tool to evaluate the dynamic effects of any future design changes. However, it did not pay attention to the way to achieve the changes of the external environment. Honeywell thermodynamic testbed can control the gas supply parameters of the thermodynamic test bed in real time through the mathematical model of the engine. The temperature has a certain followability of the engine performance curve in
the flight envelope. However, the temperature hysteresis caused by the heat capacity of the test tube cannot simulate the ideal engine working condition.

In this paper, we will discuss the design of the thermodynamic test stand. First, we will discuss the technical difficulties in the design of the thermodynamic test stand, and then find out the design key points suitable for the dynamic character analysis. Through the research, the feasibility of the current measures are discussed, and finally the preliminary design scheme is given based on the dynamic performance requirements of the thermodynamic testbed.

2. Technical difficulties

According to the instantaneous data of the maximum change rate of the air outlet temperature, the rapid rise characteristic of the engine bleed air temperature is plotted. All of these data can be found in aircraft air bleed system function interface control file (FICD). As shown in figure 1, High-pressure bleed air temperature is usually 500 °F ~ 1200 °F and Medium-pressure bleed air temperature range from 200 °F to 700 °F. Furthermore, based on the maximum heating rate and the most severe heating curve facing the aircraft's control system, the maximum inlet temperature rise rate of the high-pressure gas supply meets 235.8 °F / s. The temperature should increase from 580 °F to 1100°F in 5s and stabilize within 10s. For the medium-pressure, the gas supply meets 182.5°F / s and the temperature should increase from 300 °F to 1100 °F in 5s and stabilize within 10s. Therefore, in order to truly simulate the working condition of the engine, the primary problem is that the high and medium pressure air supply lines of the testbed must have a sufficiently high supply air temperature and meet the requirement of rapidly heating for the inlet air of the test piece.

![Figure 1. Engine bleed air temperature rapid rise characteristics.](image)

At present, the commonly method of heating air are used: direct heating of electric heater and indirect heat transfer of high temperature gas. As gas combustion temperature control technology is not mature, and the temperature regulation accuracy is not too high, the electric heating has been used to obtain high-temperature heat source. There are two typical high-temperature air electric heaters currently on the market classified into two types for civil and aviation use. They are mainly used for the testbed in static conditions, but useful information can be found from their basic configuration and working principle for the purpose of selecting core components of the thermodynamic testbed heater.
Three-stage air heating was used in civil air heater. The temperature rise step by step and the highest temperature can reach 1500 ºF. Aeronautical air heaters are based on the Soviet electric heater, specifically used in aeronautical environmental control thermodynamic testbed. The design maximum temperature of the electric heater is below 1100 ºF. Through the comparison of the working principle and the static design indexes of the two kinds of air electric heaters, the aeronautical air heater has small heat capacity, weak thermal inertia and higher temperature rising than the civil heating in the middle and low temperature range when the airflow pressure is the same through the electric heater. In the high temperature range, with the increase of temperature, the air temperature in the isolation chamber is obviously higher than that in the middle and low temperature range. The heat dissipation to the outside increases and the thermal inertia of the structure is smaller, but the temperature rising rate significantly decreased, and the highest temperature of the electric heater outlet air is lower. In contrast, civilian electric heater makes it less heat dissipation due to the use of insulation material, and electric heater outlet air temperature is higher. As dynamic performance is not the focus of designers and users of electric heaters, there is no credible data to support the dynamic performance design of the testbed. Through the time-consuming analysis from normal temperature to maximum temperature, it is impossible to directly use the electric heater to meet the dynamic performance requirement of the testbed. One of the technical difficulties is how to achieve rapid and fast heating demand by using existing electric heaters.

In addition, the change rate of the fastest temperature rise supposed by the thermodynamic testbed should be consistent with the actual situation of the system. In order to achieve such dynamic properties, the thermal inertia and the volume inertia of the rear end of the heater are the key factors. Such inertial cause a large delay in temperature change and make the temperature control system produce some overshoot and fluctuation. Therefore, the originally difficult rapid heating performance become more difficult. In order to illustrate the effect of thermal inertia and volumetric inertia on dynamic changes in supply air temperature, a simulation description is given. The simulation assumes that the duct is stainless steel with an inner diameter of 6 in and a thickness of 0.375 in. the temperature characteristics of duct were compared in different length (10 ft, 20 ft and 30 ft), different initial wall temperature and different supply temperature. As shown in figure 2, the results show that the shorter the duct, the better the dynamic response of the output airflow temperature when the same supply temperature, the same initial wall temperature and the same air flow in the duct. The higher the supply air temperature, the better the dynamic response of the duct output airflow temperature response. Therefore, in order to guarantee the inlet temperature rising rate, it is helpful to increases the temperature of the outlet air of the electric heater and minimize the length of the duct between the heater and the inlet of the test piece. This study also found that pre-heating of the duct can also speed up the dynamic response of outlet air temperature.

![Figure 2. The temperature characteristics of duct](image)
3. Scheme design of thermal dynamic testbed
The dynamic performance test of the environmental control system requires that the inlet air of the pipeline should be heated rapidly. The testbed must overcome the thermal inertia and volumetric inertia. Based on the existing products, the testbed should have the ability of fast air heating and rapid temperature respond through system engineering theory.

3.1. Fast air heating
At present, the fastest temperature rise rate of the electric heater in the low temperature range can only reach 50 °F /s. Due to the increase of the external heat loss in the high temperature range, the temperature rise rate is greatly decreased, which are far from meeting the requirements of the environmental control system demand for dynamic performance testing. On the basis of the static test method, drawing on the system configuration method of aircraft cockpit temperature control, the rapid response of the temperature is achieved by the method of hot and cold gas blending. As shown in figure 3, the specific method is as follows: the test bench adds a bypass in the front of the electric heater, by adjusting heater front valve and bypass valve, one part of the supply air flow through the electric heater and another part flow through the bypass to maintain normal temperature. The two parts were mixed at the rear end of the heater. Through changing the ratio of hot and cold air mixture, we can achieve the purpose of rapid temperature control. During the test, the electric heater kept the outlet air temperature at the maximum temperature that the electric heater could reach. The cold air regulating valve in the test tube was normally closed and the hot air regulating valve was always open. This system overcomes the inherent characteristics of the slow rate of temperature rise of the electric heater and ensures that the gas supply to the test pipe inlet has a faster heating rate.

![Figure 3. Fast air heating principle diagram.](image)

In order to solve the problem of thermal inertia of the pipeline connecting the outlet of the electric air heater and the control system of the aircraft control system, two aspects need to be taken. On the one hand, under the premise of ensuring the safety of the testbed, the distance between the outlet of the electric heater and the interface of the aircraft loop control test piece should be shortened as much as possible to reduce the inertia and retardation of the system; on the other hand, the outlet air temperature of the electric heater should be increased to satisfy pipe heat capacity requirements.

3.2. Rapid temperature respond
In the take-off phase, the aircraft engine thrust rapidly increased within 10s and high pressure air outlet port was rapid heating. According to the heating curve shown in figure 1, the analysis shows that the temperature change during high and medium pressure switching is similar to the step response, and the testbed can achieve the dynamic performance by switching different air supply lines just as shown in figure 4. During test preparation, the two air supply line of the testbed were used to simulate the initial upstream temperature before and after the temperature change. One air supply line of the testbed has been in the emptying stage before getting testbed control instructions. There was 2-3s delay between valve changes and the response of the step signal slightly slowed down which was closer to the true simulated speed heating process.
4. Conclusion
In this paper, the necessity of studying the dynamic performance of the control system is discussed firstly. The design of thermodynamic testbed makes it possible to study this dynamic characteristic in the laboratory. This paper illustrates the technical difficulties of the dynamic performance of the testbed, and the primary problem is that the high and medium pressure air supply lines of the testbed must have a sufficiently high supply air temperature and meet the requirement of rapidly heating for the inlet air of the test piece. Because the current electric heater cannot meet the requirements of the dynamic performance test of the environmental control system at the heating rate, a hot and cold blending method is proposed in this paper to achieve the rapid response of the temperature. Through the switching of different air supply lines, the process of rapid temperature rising can be achieved.

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