Study on the Measurement Technology of Temperature Field at the Outlet of the Precooler in the Bleed air system of Civil Aircraft

Xiaodan Huang*
Shanghai Aircraft Design and Research Institute of Commercial Aircraft Corporation of China Ltd, Shanghai, 201210, China

*Corresponding author e-mail: huangxaiodan@comac.cc

Abstract. In view of the phenomenon of uneven temperature field in the hot side outlet pipe of the precooler in the Bleed air system of civil aircraft, three thermocouple layout schemes were put forward. By comparing and analyzing the changes of the flow field in the pipe before and after the installation of the three schemes, the most effective scheme was determined. At the same time, the temperature uniformity before and after the mixing device at the outlet of the precooler is compared and analyzed, and the method of increasing the turbulence device to improve the accuracy of the average temperature measurement of the precooler is put forward.

Keywords: Civil Airliner, Bleed Air System, Precooler, Non-Uniform Temperature Field, Turbulence Device

1. Preface
Since large temperature difference based heat transfer, cross flow structure and reduced head diameter structure of the precooler in the Bleed air system of civil aircraft, an obvious non-uniform temperature field is caused in the outlet pipe of precooler hot side [8]. It is concluded from the experience of previous Bleed air system that the temperature field at the outlet section of the precooler hot side shows obviously non-uniformity. At some working case, the temperature difference at the outlet section of the hot side of the precooler can reach up to 240 °C, which will temperature control of the system and affect the normal realization of the temperature regulation of the Bleed air system[9]. It is precisely because of the existence of non-uniform temperature field characteristics, the average temperature cannot be accurately measured, resulting in the experimental check of the thermal and dynamic performance of the precooler becomes difficult to achieve accurately.

This paper analyzes and studies the above two issues:
1) Studying the number and mode of the thermocouple arrangement on the temperature measuring surface of the hot side outlet pipe of the precooler, so as to obtain more information on the temperature field of the hot side outlet pipe with as little impact on the flow field as possible[1]. In order to verify the simulation analysis of non-uniform temperature field based on the test results.
2) Studying the test method of the thermodynamic performance of the precooler and the scheme of improving the uniformity of the temperature field at the outlet of the hot side, so as to obtain a more accurate average temperature of the outlet pipe and realize the measurement of the performance of the precooler.

2. Test Method for Measurement of Non-Uniform Temperature Field in Hot Side Outlet Pipe of Precooler

2.1. Test Temperature Measurement Scheme
The temperature of multiple points in the pipe was measured by the evenly spaced thermocouple, and the temperature field in the pipe was characterized by myopia. Through Fluent simulation calculation, the influence of the arranged thermocouple on the flow field and temperature field in the pipeline was analyzed, and the layout scheme was optimized to ensure that the thermocouple would not have obvious influence on the original flow field and temperature field, so as to ensure the accuracy of measurement.

In order to reduce the influence of thermocouple on the original flow field and ensure that the thermocouple has sufficient strength, the armored thermocouple is selected. The length and diameter of the measured section of the test piece are consistent with the length and diameter of the sensor used for measuring the hot side outlet pipeline of the real installed precooler [3].

In order to arrange as many thermocouples as possible without obviously affecting the temperature field and flow field inside the pipeline, so as to capture more characteristics of temperature field in a single test and reduce the number of tests, three thermocouple layout schemes were proposed, as shown in Figure 1.

![Figure 1. Three types of arrangements of thermocouple](image)

2.2. Simulation Calculation of Flow Field on Temperature Measuring Surface
According to the above three thermocouple layout schemes, the flow field and temperature measuring section of the outlet pipe of the hot side were simulated and calculated respectively, and the influence of the thermocouple layout on the original flow field was analyzed [2]. Since the air in the pipe does not exchange heat with the outside world, the internal temperature field changes from the forced convection of the air, that is, the change of the flow field. If the thermocouple does not show a significant impact on the flow field, it will not have a significant impact on the temperature field. Therefore, the influence of the thermocouple on the temperature field is not analyzed in this simulation.

Setting of FLUENT Parameter
In the simulation calculation, the hot side air flow is 2kg/s with the pressure standing at 435kPa. At this time, the air density equals 1.293×(actual pressure/standard physical atmospheric
pressure)*((273.15/ actual absolute temperature). After put in the value, the air density is 2.0119kg/m³, and the diameter of the hot side pipe is 0.1016m. The mass flow rate is converted to speed as:

\[
2/(2.0119*0.0508*0.0508*\pi)=122.6\text{m/s}
\]

Looking up the table, it is found that the dynamic viscosity of air is 3.3292*10^-5. The two settings are applied to the settings in the Materials-Fluid-air.

(1) Setting of discrete equations

The governing equations were discretised by finite volume method, the velocity and pressure were coupled by SIMPLE algorithm on the in-situ grid. The turbulence governing equation is solved by the standard model \( k-\varepsilon \), and the discrete governing equation is solved by the uncoupled implicit algorithm.

(2) Boundary conditions and convergence conditions

Inlet conditions:

In this example, air can be considered as an incompressible fluid. The change of fluid volume is ignored and the density of gas is considered as a constant. Therefore, the boundary condition of the inlet is set as the velocity inlet, and the flow velocity and initial pressure of the inlet are given.

Outlet conditions:

Since the structure of the hot-side outlet pipe and the measuring section determines its internal pressure drop, there is no need to set back pressure in the outlet boundary condition, so the outlet boundary condition is set as free outflow.

Convergence conditions:

The absolute value of residuals is less than 10^-3.

Simulation Results and Analysis

Among the three thermocouple layout schemes, the influence of thermocouple on the flow field on the temperature measuring surface is shown in Table 1 below.

| No. | Arrangement of thermocouples | Thermocouples not arranged |
|-----|-----------------------------|----------------------------|
| Scheme 1 (Temperature measuring surface near core body) | ![Image](image1.png) | ![Image](image2.png) |
| Scheme 1 (Temperature measuring surface away from the core body) | ![Image](image3.png) | ![Image](image4.png) |
| Scheme 2 | ![Image](image5.png) | ![Image](image6.png) |
| Scheme 3 | ![Image](image7.png) | ![Image](image8.png) |

By comparing the flow field of each temperature measuring surface with and without thermocouples, it can be seen that:

A) Since the diameter of the thermocouple protection tube is only 2mm, which is far smaller than the diameter of the hot-side outlet pipe section, the arranged thermocouples have no obvious influence on the overall flow field.
B) Due to the obstruction of thermocouples, the air velocity nearby increases significantly, leading to changes in the local flow field, but each thermocouple has different influences on the nearby flow field. In Scheme 2, the flow field around points 1, 2, 3 and 6 does not change significantly, while the flow field around points 4 and 5 showed significant changes. This part of measurement data can be deleted during test data processing.

C) The flow field on the temperature measuring surface near the core in Scheme 1 is basically the same as that in Scheme 2, indicating that the flow field on the temperature measuring surface is not affected by the thermocouple arrangement on the temperature measuring surface far away from the core.

D) The flow field difference between the two temperature measuring surfaces in Scheme 1 is mainly reflected in the point 5. Because of its deep insertion, significant disturbance is generated to the nearby flow field. The flow field around the other points is basically the same.

E) Although the arrangement of thermocouples in Scheme 3 is the least, the first point of it produces obvious disturbance to the flow field, which will lead to its inability to accurately measure the original temperature field. Its effective temperature measuring points are too few.

Based on the above simulation results and the analysis of the influence of the thermocouples in the three schemes on the original flow field, it can be seen that the distance between the two temperature measuring surfaces in Scheme 1 is small and the flow field is basically the same. Therefore, it is of no practical significance to arrange two temperature measuring surfaces. In the third scheme, the reduction of the number of thermocouples did not significantly weaken its influence on the original flow field, but the number of effective temperature measuring points is reduced for one. Four of the six thermocouples arranged in the second scheme have no obvious influence on the nearby flow field, so they can be used as effective temperature measuring points. Comparison of the three schemes is shown in Table 2.

Table 2. Comparison of effective temperature measuring points of three thermocouple layout schemes

| No.   | Number of thermocouples arranged | Effective temperature measuring point |
|-------|----------------------------------|---------------------------------------|
| Scheme 1 | 12                               | 4                                     |
| Scheme 2 | 6                                | 4                                     |
| Scheme 3 | 2                                | 1                                     |

Figure 2. Scheme of non-uniform temperature field of precooler in measurement verification and test

For the test of non-uniform temperature field at the pre-cooling outlet, the arrangement of thermocouple in Scheme 2 will be adopted, as shown in Figure 2. After the completion of a set of tests, the temperature measurement section can be rotated at a fixed angle to obtain more characteristics of the temperature field, which can be used to verify the temperature field simulation calculation method.

3. Study on Test Method of Thermodynamic Performance of Precooler

It is difficult to measure the average temperature accurately because of the uneven temperature field in the outlet pipe of the hot side of the precooler. The main content of this section is to study the method of improving the uniformity of temperature field of outlet pipe of precooler hot side, to obtain a more accurate average temperature of outlet pipe and realize the test of the performance of the precooler [4].
3.1. Heat Transfer Performance Test Scheme of the Precooler

In the performance test of the precooler, the heat transfer characteristics of the precooler need to be measured. Because of the cross flow structure of the precooler, the reduced diameter structure of the head and the large temperature difference between the cold and hot air inlet, the temperature field in the core body and the outlet pipe of the precooler is obviously non-uniformity. The traditional temperature measurement method of placing thermocouples directly inside the pipeline is difficult to obtain the average temperature at the outlet, so it is impossible to carry out an accurate evaluation of the performance of the precooler [5]. Consider adding a turbulence device on the hot side outlet pipeline of the precooler, as shown in Figure 3, to make the airflow rotate, force it to mix, and improve the uniformity of temperature field in the pipeline. Then the traditional thermocouple arrangement scheme is used to measure the outlet temperature of the hot side air.

![Figure 3. Schematic diagram of spoiler results](image)

In this test, the turbulence device adopts the principle of mechanical whirlwind, which forces the air to mix in the pipe by the rotation of the air passing through the fixed helical vane cyclone. The turbulence device is composed of a cyclone and an outer cylinder, which are connected by welding. Since the maximum flow rate of the hot side airflow in this test can reach 2kg/s, the flow resistance of the cyclone needs to be optimized when the airflow is fully disturbed [7].

The design is optimized based on the traditional 6-blade whirlcone, the number of vanes is reduced, and the linear guide section is added at the inlet. The simulation results show that the flow resistance of the new four-blade cyclone is only 60% of that of the old cyclone. When the gas flow rate reaches 2kg/s, the flow resistance of the cyclone with the new structure is about 100kPa, which is lower than the flow pressure at the hot side inlet of 435kPa, and it will not cause significant influence on the performance test of the precooler [6].

3.2. Simulation Calculation of Outlet Pipeline

Consider the influence of the structure of hot-side inlet and outlet head and hot side outlet pipe on the flow field, the whole simulation of the hot side channel of the precooler was carried out. The air flow was set as 2kg/s and the pressure was 435kPa. A temperature field with a temperature difference of 100°C was set on the outlet section of the hot side outlet head of the precooler. The temperature field on the temperature measuring surface of the outlet pipe was simulated and calculated to investigate the improvement effect of the turbulence device on the uniformity of the temperature field of the outlet pipe. See Figure 4 and figure 5.

![Figure 4. Temperature field (In front of whirlcone)](image)
Based on the simulation results of temperature field, the temperature of the outlet cross section of the hot-side outlet head was 718K~818K with the temperature difference at 100K during the simulation calculation, as shown in Figure 6. After being stirred by the whirlcone, the temperature on the temperature measuring surface is 772K~775K, and the temperature difference only reads 3K, as shown in Fig. 7, which shows that the whirlcone can significantly improve the uniformity of the temperature field in the outlet pipeline[10]. Since there are 6 thermocouples arranged on the temperature measuring surface, the more accurate average temperature of the outlet pipe can be obtained by taking the average value of the measured value.

4. Conclusion
In this paper, a sensor arrangement method to obtain more effective temperature field information as far as possible is proposed by studying the number and mode of the thermocouple arrangement on the temperature measuring surface of the outlet pipe of the hot side of the precooler. At the same time, the scheme of improving the uniformity of the temperature field at the outlet of the hot side is obtained through the analysis of the temperature mixing characteristics of the outlet of the precooler, which strongly supports the performance test of the precooler.

References
[1] Xu Yi, Huang Mingjing, Cheng Xinqi, Ma Hongwei. Temperature Measurement Technology of Coated Thermocouple on Aero Engine Turbine Blade. Aero-engine, 2021, 47(01):91-95.
[2] Pan Junhua. Working Principle of Temperature Measurement Thermocouple and Its Application in Field. Internal Combustion Engine & Parts, 2020(04):181-182.
[3] Zhang Lixin, Xiao Xiang, Chen Jie, Tang Qingsong, Ren Kan. Research on Precious Metal Sleevng Thermocouple for Aviation. Sensor World, 2020,26(08):27-30.
[4] Gao Yuan, Chen Yuchun, Shi Xinling. Calculation Model of SABRE Precooler and Its Application in Machine Model. Journal of Propulsion Technology:1-9[2021-06-25]
[5] Duan Kaiyong, Zhang Qingying. Thermocouple Temperature Measurement Method Based on Digital Cold End Compensation. Science and Technology Association Forum, 2008(02):41-42.
[6] Zhao Lixin, Dai Jiaxin, Guo Xianchen. Optimization of Operation Parameters for Vane Hydrocyclone. Fluid Machinery, 2013, 41(10):7-9+52.
[7] Zeng Zhuxiong, Liu Yingli, Wang Hao yuan, Zhang Yongqi, Zhang Jiguo. Combustion flow analysis of standing vortex combustor with built-in spoiler. Journal of Thermal Science and Technology,2021,20(01):40-47.
[8] Cui Jianhua, Yu Qiong, Zhang Lin, Gan Ming, Zhuang Tingxiang, Wu Chen. Research on Non-uniform Temperature Field and Temperature Effect in Shandong Marine Training Center. Building Structure, 2017,47(18):99-104.
[9] Yang Bo, Zheng Yuanming, Ni Min. Experimental Study on Hollow Gas Density Distribution in Non-uniform Temperature Field. University Physics, 2011, 30(06):42-46+51.
[10] Yang Zhaoxin, Zeng Xing, Zhang Wenqing. Dynamic Characteristics of Thermocouple in Gas Medium. Journal of Aerospace Power, 2020,35(12):2514-2520.