Simulation and Calculation of Modular Integrated Design of Heat Exchanger

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Abstract. The modular integrated design of the five heat exchangers of the air-conditioning system, auxiliary cooling system and air quasi-system in the aircraft environmental control system resulted in four plans: comprehensive plan 1, comprehensive plan 2, comprehensive plan 3, and comprehensive plan 4; Use MATLAB/Simulink to simulate and model the ram air system components including heat exchangers and build a ram air full-channel simulation platform; Build a single-channel heat exchanger test platform to verify the validity and correctness of the simulation platform; The simulation platform is used to calculate the performance of the full envelope of the four plans.

1. Introduction

1.1. Research Background
The aircraft ram air integrated system needs to meet the refrigeration requirements of five subsystems including the air conditioning temperature control system (ACS), auxiliary cooling system (SCS), air preparation system (APS), emergency ventilation system and PACK cabin ventilation system. Among them, the emergency ventilation system and the PACK cabin ventilation system do not contain heat exchangers, which are mainly used in ACS, SCS and APS systems. Therefore, the design of the heat exchanger integration scheme is only carried out for the three subsystems of ACS, SCS and APS. Among them, the ACS and APS heat exchangers adopt air-air actuators with ram air as the cooling medium; SCS condensers adopt air-liquid exchanges. Heater uses refrigerant as cooling medium.

The air-conditioning temperature control system is used to maintain good environmental conditions in the aircraft cabin (cockpit, passenger cabin, cargo compartment, etc.) under different external environments and flight conditions. It not only provides a comfortable environment for the crew and passengers, but also provides equipment and cargo on the aircraft. Safe use and storage environment. The auxiliary cooling system adopts a combination of evaporative cycle refrigeration and liquid cooling cycle. The air preparation system is a subsystem of the nitrogen generation system, which uses ram air to pass through a heat exchanger to reduce the temperature of the high-temperature and high-pressure bleed air to meet the intake requirements of the nitrogen generation system.

1.2. Comprehensive plans
Due to the different functions of the three subsystems (air conditioning temperature control system, air preparation system and auxiliary cooling system), the temperature changes of the ram air after passing
through the heat exchangers of the three systems are different. Generally speaking, ACS (air conditioning temperature control system)>APS (air Preparation system)>SCS(auxiliary cooling system), so the sequence of the three system heat exchanger modules is SCS (auxiliary cooling system)→APS (air preparation system)→ACS (air conditioning temperature control system) [1]. On the basis of referring to the integrated form of heat exchangers of the current models, four schemes were designed: comprehensive plan 1, comprehensive plan 2, comprehensive plan 3, and comprehensive plan 4.

This paper will conduct modular integrated design for the five heat exchangers of the air conditioning system, auxiliary cooling system, and air quasi-system in the aircraft environmental control system; build a system-level ram air full-channel simulation modeling verification platform; build a single-channel replacement The heat exchanger test platform verifies the validity and correctness of the simulation platform; the simulation platform is used to calculate the full envelope performance of the four comprehensive plans.

2. Simulation platform

The full-flow simulation platform is mainly built using Matlab-Simulink (2018a). The simulation platform mainly includes the mathematical model of the throttle, the mathematical model of the phase change of the water jet[2][3], the mathematical model of the air-to-air heat exchanger with different combinations, the mathematical model of the stamping cavity, and the mathematical model of the fan head. The model is composed of multiple sub-models. Each mathematical model is built according to its corresponding physical principles and mathematical formulas. The difference between the different flow channel forms is the difference in the combination of heat exchanger, the difference in the flow channel of the cold side, and the number of fans. However, the four different combinations only need to change the corresponding parameters and connection methods to form different full-channel simulation platforms, as shown in Figure 1 to Figure 4.

3. Single-channel heat exchanger test platform

The main content of the single-channel heat exchanger test is to obtain the main performance parameters of the heat exchanger under different working conditions, including the heat exchanger cold and hot side inlet and outlet temperature, inlet and outlet pressure changes and other parameters, and compare them with the calculation results in the simulation platform. Make a comparison to verify the effectiveness of the model. The overall structure of the test bench is shown in Figure 5 and Figure 6. A temperature sensor and a pressure sensor are arranged at the inlet and outlet of the hot side and
the inlet and outlet of the cold side to measure the corresponding inlet and outlet pressure and temperature; the flow measurement of the hot side uses a vortex flowmeter, and the cold side uses a hot wire anemometer, which are respectively used for measurement. The mass flow of the hot side and the mass flow of the cold side of the heat exchanger; in order to control the flow of the cold and hot sides, the cold side fan is controlled by a frequency converter, and the corresponding cold side flow is adjusted by the frequency converter, and the hot side adopts a comprehensive environment simulation test console. The electric control valve adjusts the hot side inlet flow. The test conditions performed on the test bench are shown in the following table 1:

![Figure 5. Schematic diagram of heat exchanger test bed](image1)

![Figure 6. Physical drawing of heat exchanger test bench](image2)

| Hot side flow(Kg/h) | Hot side inlet temperature(℃) | Cold side flow(Kg/h) | Cold side inlet temperature(℃) |
|--------------------|-------------------------------|----------------------|-------------------------------|
| 500                | 155                           | 1350, 2350, 3350, 4350, 5000 | 20                            |
| 500                | 175                           | 1350, 2350, 3350, 4350, 5000 | 20                            |
| 500                | 197                           | 1350, 2350, 3350, 4350, 5000 | 20                            |

![Figure 7. Hot edge out temperature model verification(155℃, 175℃, 195℃)](image3)
Figure 8. Cold edge out temperature model verification (155°C, 175°C, 195°C).

Figure 9. Validation of cold-side flow resistance model (155°C, 175°C, 195°C).

Compare the calculation results of the simulation platform with the test results: Figures 7-9 show the model verification of the heat exchanger's hot-side temperature, cold-side temperature, and cold-side flow resistance of the heat exchanger in the simulation platform. The calculation results can be obtained from the comparison results. It is basically the same as the test result or the difference between the two results is within the acceptable range. The single-channel heat exchanger test verified the correctness and validity of the mathematical model of the heat exchanger in the simulation platform to ensure the reliability of the subsequent performance calculation results.

4. Full envelope performance calculation

For the four design schemes, there are five heat exchangers in each design scheme: ACS primary heat exchanger, ACS secondary heat exchanger, SCS heat exchanger, APS primary heat exchanger, APS secondary heat exchanger. The size, structure, and placement form are different, but the amount of heat exchange to be provided during the full-envelope flight is certain, so the amount of heat exchange provided for any scheme must meet the requirements. In order to make the chart concise and easy to understand, the serial number corresponding to each flight mission is used as the X-axis, and the required indicators are used as the Y-axis to draw. As shown in Fig. 10-13, the calculation results of heat transfer of five heat exchangers are shown, and Fig. 14-18 are the calculation results of flow resistance of five heat exchangers.
4.1. Calculation of heat exchange for full-covered line

![Figure 10. ACS PHX heat exchange](image1)

![Figure 11. ACS MHX heat exchange](image2)

![Figure 12. SCS heat exchange](image3)

![Figure 13. APS MHX and PHX heat exchange](image4)

4.2. Calculation of flow resistance of full envelope

![Figure 14. ACS MHX flow resistance](image5)
5. Conclusion

- Referring to the aircraft in service and based on the heat exchange, four flow channel schemes are designed: comprehensive scheme 1, comprehensive scheme 2, comprehensive scheme 3 and comprehensive scheme 4;
- The simulation platform for comprehensive plan 1, comprehensive plan 2, comprehensive plan 3, and comprehensive plan 4 was established using Matlab–Simulink (2018a);
- The purpose of the single channel heat exchanger test is to verify the correctness and effectiveness of the mathematical model of the heat exchanger;
- Using the whole channel simulation platform, the heat transfer and flow resistance of five heat exchangers with four different schemes are roughly calculated;

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