The impact and application of aircraft cooling systems on aircraft

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Abstract. Aircraft cooling systems were developed along with steam aeroplanes. In the state of high-speed operation, any temperature imbalance will cause an irreversible situation. In the evolution of generations of aircraft, aircraft cooling systems should also be upgraded and gradually returned to two categories, air cycle cooling system and evaporation cycle cooling system. The advantages and disadvantages of the two systems are obvious, and they complement each other, so in the modern background, there are also examples of some large passenger aircraft such as Airbus 350 combining the two cooling systems, which will also become the future development trend.

Keywords: Aircraft, cooling system, evaporation cycle, air circulation.

1. Introduction

It is well known that internal combustion engines, engines, and other hardware for aviation applications need to operate within a specific temperature range to avoid structural damage, knocking, and loss of efficiency during combustion [1]. On July 17, 1996, the fuel tank of TWA Flight 800 (TWA 800) in the United States, due to poor heat dissipation, the temperature of the oil and gas in the fuel tank quickly entered the combustible range during the take-off and climb stage, and there was a potential ignition source in the fuel tank, and finally exploded in the air, and all the people on board were killed. A good cooling system is the most basic guarantee for aircraft safety [2]. At the same time, the cooling system can help the engine reduce the possibility of overheating, resulting in lower losses and fuel consumption, and a longer service life [3]. In the 1940s, the prototype of today's mainstream air refrigeration system appeared. Evaporative cooling systems were developed on this basis, and the aircraft cooling process can be carried out with the help of two different technologies. One is a global cooling system, and the other is a local cooling system [4]. Since modern times, with the continuous progress of aircraft manufacturing technology, aircraft have also been widely used in a variety of applications and fields, and the demand for cooling power in the aviation industry has gradually increased, so multiple versions of cooling systems have been extended for different fields [5]. The cooling systems used in aircraft are mainly divided into two types, one is the air cycle cooling system, and the other is the evaporation cycle cooling system. Air circulation cooling systems are popular for their energy saving and low demand threshold, but there are also problems such as poor cooling effect and noise pollution. On the contrary, evaporative cycle cooling systems are more efficient and environmentally friendly, but high consumption is a major problem in application. This paper will compare these two types of aircraft cooling systems and discuss the practical application of their principles.

2. Classification of cooling systems

2.1. Air circulation cooling system

The air circulation cooling system is in the high air, using the speed of the aircraft itself to achieve the rapid circulation of air to dissipate heat. The system consists of two parts of the gas pipeline, the cold channel and the hot channel. The gas in the two pipelines comes from the compressor of the engine. The pilot will rotate the temperature adjustment knob of the air conditioning panel to the appropriate position according to the seasonal characteristics and the special needs of the route. After the temperature controller receives the pilot's input instructions, the received pipe temperature sensor is compared with the cabin temperature sensor to finally determine whether to heat up or cool down, to control the proportion of cold air and hot air to the mixing chamber and obtain the cockpit air that meets the physiological and working needs of the human body. As early as 1944, the United States applied it to P80 fighter jets. However, there are many problems, such as the decline in the stability of the aircraft and the difficulty of operation [6]. This is mainly due to the disturbance area of airflow difference outside the main part of the fuselage, which makes the plane bumpy. However, the air circulation cooling system is still widely used for many reasons such as environmental protection, low manufacturing cost, low technical requirements and a wide range of applications. The main principle is that the rotating propeller will let the air enter the head, and under the guidance of the deflector, the air passes through the exhaust pipe and cylinder. Finally, it is discharged by the port [7].

The air circulation refrigeration system consists of a compressed air source, a heat exchanger and a turbine expander. The cockpit supercharger driven by the engine or the high-temperature and high-pressure air directly activated and drawn by the heat exchanger first passes through the heat exchanger, transmits the compressed heat to the cooling medium (the cooling medium of the heat exchanger is generally the external ambient air and fuel), and then flows into the turbine for expansion, and drives the turbine to rotate, driving the coaxial compressor or The fan converts thermal energy into mechanical work, and the temperature and pressure of the air itself are greatly reduced in the turbine outlet, to obtain cold air that meets the temperature and pressure requirements. After mixing with the hot air in a certain proportion, it can lead to the cabin providing a comfortable environment and supercharge.

The air circulation cooling system can be simply divided into three categories according to the type of turbine cooler in the cold circuit system: turbine fan type, turbine compressor type and turbine compressor fan type. Among them, the turbine compressor fan refrigeration system is a combination of the first two, combining the advantages of the first two.

2.2. Evaporative cycle cooling system

The emergence of the evaporative circulation cooling system is a long way. Since Linde, a professor at the Munich Institute of Technology in Germany, invented and designed the first refrigeration machine with ammonia as the refrigeration quality in 1877, its refrigeration technology principles and process methods have been changing to this day. The difference is that the refrigeration quality has been changed. From ammonia to freon, and from freon to non-fluorine refrigeration. Nowadays, the air refrigeration system is relatively mature, and an air evaporation mixed refrigeration system combining two cooling methods has also been developed in modern times. The evaporation circulation refrigeration system is composed of an evaporator, condenser, compressor, expansion valve, etc., of which the compressor is the core component of the system. The working process is that the refrigerant compressed by the compressor enters the condenser in gaseous form to cool down and become a high-pressure liquid under high-pressure conditions. Then, according to the temperature of the outlet of the evaporator, the flow rate of the refrigerant in the expansion valve is adjusted, so that the gaseous refrigerant can be refrigerated in low-pressure liquid after passing through the expansion valve. The agent enters the evaporator again, absorbs the heat of the surrounding air in the evaporator, turns it into low-pressure steam, and then enters the compressor for the reciprocating cycle. The working principle of this system is like that of a heat pump, which achieves the cooling effect by extracting heat from the low-temperature medium and discharging it into the higher-temperature medium. The refrigeration capacity range of the evaporation circulation refrigeration system is usually between 3 and 7, and its refrigeration effect depends on the working state of the evaporator, especially the precise control of the refrigerant flow rate injected into the evaporator. The thermal expansion valve adjusts the refrigeration efficiency of the evaporator by controlling the flow rate of the refrigerant sprayed into the evaporator, ensuring that the refrigerant is completely evaporated when it reaches the outlet of the evaporator, to avoid the overheated refrigerant flowing through the evaporator outlet and affecting the refrigeration effect [8]. Compared with the air-cooling system, the evaporation cooling system is more complex and changeable, so it is more used in large aircraft, for example, to achieve better refrigeration effect, such as some civil passenger aircraft, the main purpose of which is to ensure that the electronic equipment compartment has good cooling conditions.

2.3. Comparison between the two cooling systems

Compared with the two mainstream cooling systems, mainstream refrigeration on aeroplanes adopts air refrigeration circulation. Its advantages are the environmental protection of the first refrigeration quality and no phase change. Air is a natural quality, non-toxic and harmless, has no destructive effect on the environment, and can be freely obtained at any time. In the refrigeration cycle, air only plays the role of transmitting energy, and neither its chemical composition nor its physical phase changes, which is the most obvious feature that distinguishes it from the refrigeration cycle of other working matter as a refrigerant. An energy-saving direct cooling system is adopted. Even if the air is a refrigerant, it is a cooling agent. No heat exchanger is required for cooling. Cold air directly enters the environment that needs to be cooled to eliminate the heat load, and the system is positive. It is used in aviation, collecting materials on the spot, eliminating the replacement of a separate compressor with the compressor of the turbojet engine, and solving the problems of cabin supercharging and air exchange. The second refrigeration range is wide, and the operation performance at low temperatures is excellent. The air refrigeration circulation can meet the requirements of minus 140 degrees above zero degrees Celsius, especially at below -72°C, its refrigeration performance is better than that of the evaporation circulation system. When modern large aircraft operate from the ground to a height of 10,000 metres, the temperature changes greatly, so the wide temperature refrigeration range of the air refrigeration circulator just meets its Requirements. The third air refrigeration equipment is highly reliable and easy to maintain. The air refrigeration device has a simple structure, high reliability and good safety. The refrigerant can be freely replenished anytime and anywhere, and there is no need to worry about leakage. In addition, the air refrigeration circulation device is easy to disassemble and move, and there is no need to recycle refrigerant, which is convenient for maintenance. However, the evaporative cooling system is more efficient. It mainly applies the principle of water evaporation and heat absorption to take away heat. Usually, this system includes the evaporation of water in a porous medium or using the evaporative latent heat of water to cool the equipment or space through direct contact. During evaporation, water is converted from liquid to gaseous, which absorbs a large amount of heat energy, so it can effectively reduce the temperature [9]. Therefore, the system has a stronger heat exchange capacity and achieves efficient cooling under simple machinery. Correspondingly, the air circulation cooling system uses the flow of air to release heat. As a cooling medium, the efficiency of air is much lower than that of water, and the effect under high-temperature conditions will be greatly reduced. [10] But the structure is simple and suitable for most display conditions. Nowadays, it is widely used.

3. Specific applications of aircraft cooling system

3.1. Hypersonic aircraft cooling system

Aircraft larger than Mach 6 can become hypersonic aircraft. At such a high speed, the violent friction between the surface of the aircraft and the air produces extremely high heat, causing the surface temperature of the aircraft to rise sharply, usually more than 1,000 degrees Celsius. Hydrogen is usually selected as fuel and aluminium as the fuselage. And without a high-efficiency cooling system, accidents are extremely prone to occur. Among them, there are three main technical means to ensure safety, namely air membrane cooling technology, active thermal protection technology and pneumatic thermal recycling.

Air membrane cooling technology has the advantages of simple structure, reusability and good cooling performance. This technology isolates the solid fuselage surface from the high-temperature airflow by forming a coolant film on the surface of the aircraft, preventing the fuselage from overheating damage due to direct contact with high-temperature airflow. Air membrane cooling technology has been effectively applied to combustion chambers, turbine blades and other special thermal protection engineering fields, significantly reducing the thermal load and friction resistance of the wall of ultra-supersonic aircraft, as well as the temperature of the hot end components of the power system and improving the performance of the aircraft and power system.

Active thermal protection technology has the advantages of high cooling efficiency, reusability and high reliability, which can meet the thermal protection needs of aircraft. This technology uses the heat energy generated by aerodynamic heating to realise the efficient operation of the thermal control device through autonomous pressurisation and cooling cycle. The test shows that the equipment can control the cabin temperature below 100 degrees Celsius in the first 50 minutes of flight, after which the coolant begins to boil and evaporate, transferring heat at a faster speed to achieve the best temperature control [11].

The new cooling device that recycles pneumatic heat is an innovative cooling idea, which uses the pneumatic heat generated during the flight as the driving force of the active cooling cycle to cool the aircraft through the circulation of cooling water. This device does not require complex components, such as heat pipes or booster pumps, which greatly simplifies the system structure and has the characteristics of reusable use. By optimising the design, the research team ensures that the device can be reused only by adding water before each flight. This feature can not only reduce the operating cost of the cooling system but also make the device more reliable and flexible.

3.2. Evaporation cycle cooling system of Little Eagle 500

The first test flight of the Little Eagle 500 aircraft was on October 26, 2003. It can be used as a civilian and military trainer aircraft and a commercial aircraft, which can meet the requirements of the CCAR-141 Department for commercial license training of single-aircraft pilots. The aircraft obtained the model qualification certificate issued by China Civil Aviation in October 2005 and has begun to be delivered for use. In addition, the comprehensive performance of the Little Eagle 500 aircraft has reached the advanced level of similar models abroad, and it is widely used in flight training, official flight, agriculture, animal husbandry and forestry, tourism, protection, patrol, aerial detection and photography and other navigation operations [12].

The engine of the Little Eagle 500 adopts a 6-cylinder horizontally opposed air-cooled piston engine produced by Lecomming Company in the United States, and its cooling method combines air-cooled and liquid-cooled technologies. The liquid cooling part takes away the heat generated by the engine through the coolant cycle. The cooling system adopts refrigerant R134a and is driven by engine shaft power. The coolant is forcibly circulated into the engine through the pump, absorbs heat and flows back to the radiator. In the radiator, the airflow generated by the cooling fan helps to radiate the heat in the coolant, thus reducing its temperature.

The design characteristics of its refrigeration system are reflected in its evaporation cycle refrigeration method. This refrigeration system uses the basic principle of steam compression refrigeration cycle to achieve the air conditioning effect of the cockpit or equipment compartment by reducing the temperature of the ventilated air or intermediate refrigerant. The power transmission element of the system is a pulley, and the DC electromagnetic clutch control system is used to connect and disconnect to ensure that the refrigeration effect meets the design requirements and actual needs. The application of this refrigeration system not only improves the comfort of the aircraft, but also ensures the normal operation of the aircraft under various environmental conditions.

The Little Eagle 500 aircraft will automatically adjust the circulation path and flow rate of the coolant according to the engine temperature through the system equipped with thermostat and other temperature control components to ensure that the engine runs within the optimal temperature range [13].

The cooling system also includes a series of auxiliary devices, such as radiator upper guard, thermostat cover, water pump assembly, etc. These devices work together to ensure the stable operation of the cooling system.

The core of the evaporative circulation refrigeration system is that it can effectively cool the internal space of the aircraft and provide a comfortable environment for passengers and crew. Through precise control and efficient energy utilisation, this system ensures the performance of the aircraft, while also considering economy and environmental protection, ensuring the safety and reliability of the aircraft. In addition, the system has also been tested and verified on the ground, proving that its application on the Little Eagle 500 aircraft is successful and effective.

4. Conclusion

Under the background of modern science and technology, the various conditions of the aircraft are constantly improved, and a good refrigeration system has become the most basic guarantee of its safety. Air circulation cooling system and evaporation circulation cooling system are the two main cooling methods. It has its own advantages and disadvantages. Now there is also a cooling system that combines the two, which is applied to large flights such as Airbus 350. Nowadays, human exploration of cooling has jumped out of the relatively traditional air cooling and liquid cooling. For example, spray cooling technology, as a new type of heat dissipation method, uses the latent heat of water vaporisation to absorb heat by atomizing water into tiny water droplets and spraying it on the heat source, to effectively reduce the temperature of the equipment. This technology is especially suitable for the heat dissipation of electronic devices with high heat flow density, such as avionics, which have high heat dissipation ability and good temperature control effects. Although the application of spray cooling technology in the field of aviation is still in its infancy, with the deepening of research and the development of technology, it is expected to play a greater role in aircraft cooling systems in the future. In the future, with the application of new materials and technologies, the efficiency and reliability of aircraft cooling systems will be further improved. For example, the application of nanotechnology may improve the thermal conductivity of the coolant, thus improving the heat dissipation ability of the whole system. In addition, the development of intelligent and automated technology will also make the maintenance of the cooling system more convenient. Through real-time monitoring and intelligent control, failures can be prevented, and the safety and reliability of the aircraft can be improved. At the same time, with the improvement of environmental protection requirements, future aircraft cooling systems may pay more attention to energy saving and environmental protection and adopt more efficient heat dissipation materials and designs to reduce the impact on the environment.

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