Application of Ejection theory in Civil Aircraft and CFD simulation of an ejector

Guangyu Bao*, Hongyu Zhu
Shanghai Aircraft Design and Research Institute, Shanghai, China

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

Abstract. The ejection theory is widely used in industrial fields such as drainage, cooling, vacuum. Many ejection devices are applied in civil aircraft due to their simple design and easy layout. This article introduces several types of ejection applications in multiple systems of civil aircrafts. Then a CFD simulation of the APU (Auxiliary Power Unit) compartment drainage ejector is conducted to analyse the influence on the drainage function by different arrangements.

1. Introduction
Many devices based on ejection theory are applied in multiple systems of civil aircrafts. These ejection devices can be used for drainage, cooling, metering, pneumatic source etc., which are flexible designed and space-saving. Systems using ejectors in civil aircrafts are introduced in this article. Then a CFD simulation aimed at optimization for ejector structure is conducted.

2. Ejection theory applied in civil aircrafts
The principle of ejection is shown in Figure 1. The high-pressure primary fluid enters the mixing area through the nozzle and mixes with the low-pressure secondary fluid. Part of the pressure energy is converted into kinetic energy. When the static pressure of the mixed fluid is lower than the total pressure of the secondary fluid, an ejection effect will be generated on the secondary fluid. During the ejection process, the ratio of the mass flow rate of the secondary fluid and the primary fluid is called the ejection coefficient, which can be used to judge the strength of the ejection effect [1].

Figure 1. Ejection theory.
2.1. Ejection application in aircraft systems

2.1.1. Ejection pumps in fuel system. The fuel system of an civil aircraft is designed to supply fuel to engines an APU. As the fuel is usually stored in two integral wing tanks, it is necessary to transport the fuel from the wing tanks to the collector tanks where fuel pumps are layout to gain high fuel supply efficiency. Ejection pumps are integrated to achieve this target and keep collector tank always full. The ejection pumps also have the function of removing excess water in the bottom of the fuel tanks.

2.1.2. Ejection tube of APU exhaust and cooling system. The APU exhaust system exhausts the gas overboard and introduces cooling air into the APU. The cooling air is introduced into the APU compartment after cooling the oil in the APU oil cooler and then exhausted overboard through the ejection tube.

2.1.3. Ejection drainage of APU compartment. During normal operation of the APU, the fuel is supplied by the aircraft fuel system. Therefore, the APU compartment may accumulate fuel droplets or steam due to leakage or other reasons. Therefore, it must be designed with a drainage function so as to prevent the fire hazard. A drainage system using an ejection joint assembly is integrated to exhaust flammable fuel droplets and steam out of the APU compartment.

3. APU ejection drainage system

The APU system of a civil aircraft can provide power and compressed air to the aircraft during normal operation. When the aircraft is ready to take off on the ground, the APU can replace the battery car to power the entire aircraft and provide air for the air conditioning system and engine start. When the aircraft engine shut down during the flight, the APU can provide backup power for the entire aircraft at a certain height and provide air source for the engines’ in-flight restart.

The drainage system of the APU compartment is introduced in this section for the CFD simulation afterwards.

3.1. Airworthiness demand

According to CCAR 25.1181, “Definition of Fire Zones”, the APU compartment belongs to the aircraft's specified fire zone. According to CCAR 25.1187 “Draining and Ventilation Requirements for Fire Zones: Every part of the specified fire zone must be able to completely drain the accumulated oil to minimize the risk of failure or failure of any component containing flammable liquid.”[2].

In summary, according to the requirements of airworthiness regulations, the APU compartment must have an effective and reliable drainage function.

3.2. Ejection drainage of APU compartment

A certain aircraft adopts the conventional layout of the APU tail cone. The APU compartment is located in the tail fuselage section of the rear fuselage. The APU device is installed in the APU compartment. The APU compartment door opens downward. The drainage structure of the APU compartment is shown in Figure 3. The head of the ejection drainage pipe is connected to the APU air intake valve to provide the ejection exhaust gas source. The duct is arranged along the stringer structure and passes through the opening hole in the skin of the APU compartment. The end of the pipe extends into the ejection joint structure installed on the APU compartment door, and ejects the APU bleed air to the outside of the aircraft [3].

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Figure 2. Ejection drainage structure of APU compartment.

The high-pressure main fluid of the APU compartment drainage system comes from the APU bleed air, which is discharged out of the aircraft along the APU compartment door drain connector assembly through the ejection drainage pipe, forming a negative pressure locally, and the potential fuel droplets or vapors are sucked into the environment outside the aircraft, thereby discharging flammable liquid [4].

4. CFD simulation of the drainage ejector

In this section, the CFD simulation calculation is performed for the drainage area of the APU compartment door to analyse the effect of the inner skin structure of the APU compartment door on the drainage function.

4.1. Geometric model and mesh

The two-dimensional geometric model is shown in Figure 3. The main structure includes the APU compartment ejection drainage pipe, the APU compartment skin, the APU compartment door, and the ejection joint assembly installed on the door. The geometric parameters adopt the real dimensions of a certain aircraft.

Figure 3. Ejection drainage structure of APU compartment.

This case mainly studies the influence of the structure of the APU inner skin on the ejection drainage, and selects 4 structures of inner skin opening diameters of 25mm, 35mm, 45mm, and no inner skin. The structured grids are built in ICEM 14.5 with the total number of 145157 and quality than 0.9. The grids in the area where the primary fluid flows through the ejection drainage conduit and the secondary...
fluid flows through the inner skin openings and entering the ejection joint area are encrypted to make the near-wall surface flow calculation more accurate.

4.2. Boundary conditions and calculation method
The boundary conditions of the calculation area are shown in Figure 4. The total pressure of the main fluid at the pressure inlet is 405000Pa and the back pressure of the pressure outlet is 101325Pa, ignoring the APU compartment pressure difference caused by APU exhaust. Material (air, Ma>0.3) chooses real-gas-peng-robinson. The calculation method uses the Coupled solution method. Under this method, the demand for computing resources and the number of grids increase linearly, and the convergence is more stable and fast. Selecting the QUICK format can reduce false diffusion errors, and has higher accuracy and stability. It is mainly used in structured grids.

4.3. CFD result analysis
The velocity field distributions of the four cases are shown in Figure 5. It can be seen that the high-pressure main fluid flows through the ejection and discharge conduit along the ejection joint as a high-speed jet. When there is no inner skin structure, the fluid is directly discharged out of the APU compartment through the ejection joint; while there is an inner skin structure, the fluid is first ejected into the inner skin and then passes through the opening. In the area between the inner skin and the APU compartment door, it flows as a vortex in a certain range. The velocity gradient performs greater as the diameter of the inner skin opening smaller and the flow more intense.
Figure 5. Velocity fields.

The pressure distribution is shown in Figure 6. It can be seen that the larger the opening in the inner skin, the smaller the hydrostatic pressure gradient of the ejection subside. Pressure gradient is smallest with no inner skin opening. This shows that the flow resistance is large when the ejection secondary fluid flows through the opening of the inner skin, while the energy loss is huge. The vortex flow of the ejection secondary fluid between the inner skin and the APU compartment also caused energy loss.

Figure 6. Pressure fields.

The ejection coefficient is calculated based on the main fluid mass flow in the ejection and the secondary fluid mass flow of the ejection assembly of the APU door. It can be seen from the figure 7 that the ejection coefficient increases with the diameter of the inner skin opening decreasing, and the ejection coefficient is the largest when there is no inner skin. By comparing the ejection coefficient, the ejection effect with the skin opening diameter of 25mmis reduced by 21.4% compared with the case without inner skin.
5. Conclusion
This article illustrates that several types of ejection applications in different systems of civil aircrafts and demonstrates the function and basic structure of the ejector composition. Then an ejection drainage system in APU compartment is introduced in detail. A CFD simulation has been conducted for different drainage structure forms. According to the calculation results, the ejection drainage can realize the drainage function of the APU compartment. An additional structure of the inner skin will weaken the ejection and drainage effect. By comparing the ejection coefficient, the ejection effect with an opening diameter of 25mm on the inner skin is reduced by 21.4% compared with the case without inner skin.

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