Experimental Study on Rapid Pressure Relief in the Cargo Compartment of Civil Aircraft

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Abstract. The rapid pressure relief device in the cargo compartment of civil aircraft can avoid the structural damage of aircraft caused by sudden pressure relief in a pressurized compartment. Based on a typical rapid pressure relief device in the cargo hold of civil aircraft, a test bench was built to carry out experimental research on the pressure magnitude and pressure relief process of the device. To simulate the real pressure relief situation of the aircraft pressurized cabin, two experimental studies of forwarding pressure and reverse pressure were carried out, and the pressure relief process of the device was analyzed. The experimental results show that the pressure relief time of the fast pressure relief device is basically the same, and the peak pressure difference of the pressure relief device is within the specified design range of $0.82 \sim 1.62$ psi. It provides method support for the research and experimental design of the same type of rapid pressure relief device in the cargo hold.

Keywords: Cargo hold; Rapid pressure relief; Experiment research

1. The introduction

In addition to the normal flight load and ground load, the pressurized cabin structure of aircraft also needs to bear a pressurized load [1]. The design of the rapid pressure relief device in the cargo hold of civil aircraft shall comply with the relevant airworthiness provisions of CCAR25.365(E) on pressurized cabin load [2]. The main purpose of the design is to avoid the structural damage caused by sudden pressure relief, which can affect flight safety. The design of a rapid pressure relief device in a cargo compartment can ensure that the pressure between adjacent pressurized compartments can be quickly balanced when the pressure drops suddenly due to structural damage to aircraft pressurized compartments, to ensure flight safety. March 3, 1974: Turkish Airlines Flight 981 crashes en route from Paris to London, killing 346 people on board. The investigation shows that the cause of the accident is the defects in the design of the cargo door, the cargo door fell off during the flight, the explosive decompression occurred in the cargo compartment, and the huge instantaneous pressure difference between the cargo compartment and the passenger compartment, which caused the collapse of the cabin floor and the destruction of other important systems of the aircraft, thus causing the accident of aircraft destruction and human death. The design and application of a quick pressure relief device in the cargo hold can avoid the occurrence of such accidents.

The theoretical research and calculation analysis of rapid pressure relief in cargo hold has been carried out at home and abroad. Yu Chengde and Bai Jie et al. conducted relevant simulation calculations and analysis for the sudden pressure relief load and pressure relief process of aircraft cabins [3-5]. Liu Huayuan et al. conducted relevant research on the influencing factors of the pressurized cabin load of civil aircraft [6]. Huo Ying et al. analyzed the design of the rapid pressure relief device in the cargo hold and the relevant provisions (including amendments) that it should comply with [7]. Zhang Xiaogang analyzed and calculated the opening time required by the rapid pressure relief device of cargo compartment with flexible extraction structure in the process of load increase by using finite element nonlinear stepwise loading method [8].

In this paper, the opening pressure and pressure relief process of the flexible extraction rapid pressure relief device in the cargo hold of a typical civil aircraft are experimentally designed and studied. To simulate the situation where the rapid pressure relief device is opened in different Advances in Engineering Technology ResearchISEEMS 2022ISSN:2790-1688DOI: 10.56028/aetr.2.1.286directions in a real pressurized cabin, two experimental studies of forwarding pressurization and
reverse pressurization are carried out.

2. Test Setting

2.1 Flexible extraction type rapid pressure relief device

The structure of the flexible extraction types of rapid pressure relief devices used in the test is shown in FIG. 1(a). Its structure is mainly composed of a titanium alloy frame, pressure relief sheet (made of glass fiber reinforced phenolic resin), and titanium alloy layering. The pressing strip is fixed on the frame through hexagonal bolts and supporting plate nuts, and the pressure relief sheet is fixed between the pressing strip and the frame. The opening force of the rapid pressure relief device is determined by the tightening torque of hexagonal bolts. The hexagon bolt tightening torque of the pressure relief device used in this experiment is (2.6 ± 0.1) Nm. The schematic diagram of the quick pressure relief device after assembly is shown in FIG. 1(b).



(a) Structure composition diagram of flexible extraction type rapid pressure relief device



(b) Schematic diagram of flexible extraction types of rapid pressure relief device after assembly

Fig. 1 Schematic diagram of flexible extraction type rapid pressure relief device

2.2 Installation of pressure relief sheet

The installation of the pressure relief sheet is crucial for the experiment. The installation of the pressure relief sheet should be carried out as follows:

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1) Loosen the hexagonal bolt that fixes the strip of the pressure relief sheet and remove the pressure relief sheet.

2) Replace the pressure relief sheet and ensure that the black installation and positioning mark line on the pressure relief sheet is consistent with the edge gap of the layering to ensure the accurate position of the pressure relief sheet.

3) When installing hexagonal bolts, the pressure relief sheet should be oriented towards the operator, and the bolt at the bottom of the left long strip should be tightened. Then, the remaining bolts should be tightened clockwise, and the torque value of hexagonal bolts should be set at (2.6 ± 0.1) Nm by using a torque wrench.

4) After the layering installation, re-check the tightening torque value of the bolts according to the bolt installation sequence to ensure that the tightening torque value is within the range of (2.6 ± 0.1) Nm.

2.3 Experimental Principle

The schematic diagram of the experimental principle is shown in Figure 2. The experimental system consists of an air compressor system, gas storage tank system, critical flow Venturi nozzle gas flow standard device, closed container, differential pressure transmitter, measurement, and control system data acquisition channel, and rapid pressure relief device, and test tools.

The air compressor system and the gas storage tank system provided the required air source for the test, and the critical flow Venturi nozzle gas flow standard device realized the gas supply regulation, the differential pressure transmitter measured the atmospheric pressure difference between the closed container and the outside world, and the data acquisition channel of the measurement and control system collected data. When the pressure difference between the closed container and the outside world reached a certain value, the pressure relief sheet was pulled out, and the rapid pressure relief device was opened quickly so that the closed container could be communicated with the outside world, and the function of rapid pressure relief was realized.



Fig. 2 Schematic diagram of test principle

To obtain the maximum pressure difference value of the pressure relief sheet, three groups of pressure relief sheets with forwarding installation and reverse installation of the rapid pressure relief device were collected. The channel acquisition accuracy of the acquisition system used in the test is $\pm 0.2\%$, and the sampling rate is 300Hz. The charging rate of the standard device is 50kg/h.

2.4 Test Contents

The main content of the rapid pressure relief test in the cargo compartment is to study the maximum pressure difference value and the pressure relief time of pressure relief sheet. The experimental conditions are shown in Table 1.

The serial	Tightening	Sampling	Inflation rate	Installatio	Number of
number	torque /Nm	rate/Hz	/kg/h	n	tests
1	2.6±0.1	300	50	Positive	3
2	2.6±0.1	300	50	Reverse	3

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3. Experimental Results

3.1 Forward installation test results and analysis

Figure 3(a) and Figure 3(b) show the schematic diagram of the fast pressure relief device after forwarding installation and opening. The experimental results of three times of forwarding installation of the rapid pressure relief device are shown in FIG. 4.



(a) forward installation of pressure relief sheet (b) after forward opening of pressure relief sheet





Fig. 4 Forward test results of pressure relief sheet

It can be seen from the pressure difference curve with time when the fast pressure relief device is installed forward that there is temperature drift error in the sensor at the initial state, and the pressure difference value is about 0.016 psi, which is negligible compared with the maximum pressure difference value. The inconsistency of the time points at which the differential pressure curve starts to increase leads to the deviation of the curve. The reason is that the time point at which the data starts to be collected is different each time, which does not affect the experimental results.

After the air filling in the sealed container, the pressure difference between the air pressure in the sealed container and the outside atmosphere increases approximately linearly with time due to the same inflation rate, and the slope of the pressure difference curve is basically the same. When the pressure difference reached its peak (1.25psi, 1.17psi, and 1.11psi in the three tests), the pressure relief sheet was pulled out, as shown in FIG. 3(b). The rapid pressure relief in the sealed vessel brought the pressure difference into equilibrium with the atmospheric pressure rapidly.

After the pressure relief sheet was pulled out, the pressure in the closed vessel was rapidly relieved, and the pressure in the vessel decreased rapidly. In the three tests of forwarding installation of the pressure relief sheet, the duration of the three pressure relief processes was 3.54s, 3.45s, and 3.41s, respectively.

3.2 Reverse installation test results and analysis

Reverse installation of a rapid pressure relief device means that the pressure relief device is installed on the closed vessel in reverse order to simulate the real pressure relief situation of the pressurized cabin of the aircraft. The schematic drawings after reverse installation and opening are shown in FIG. 5(a) and FIG. 5(b). The experimental results of three times of reverse installations of rapid pressure relief devices are shown in FIG. 6.



(a) Reverse installation of pressure relief sheet (b) after reverse opening of pressure relief sheet Figure 5. Forward installation diagram of pressure relief sheet



Fig. 6 Reverse test results of pressure relief sheet

As can be seen from the pressure difference curve with time when the rapid pressure relief device is installed in reverse, the pressure difference curve is basically consistent with the forward experiment. The peak pressure difference of the three tests is 1.36 psi, 1.22 psi, and 1.26 psi, and the pressure relief sheet is pulled out after reaching the peak value, as shown in FIG. 4 (b). The pressure difference between the closed container and the outside atmosphere quickly reaches equilibrium. The duration of three pressure relief processes in reverse installation is 3.62s, 3.51s, and 3.54s, respectively.

3.3 Data Analysis

According to the pressure range defined by the pressure relief sheet of the rapid pressure relief device at the time of withdrawal, the range of 0.82 to 1.62psi meets the design requirements. For forward and reverse installation, the peak pressure statistics when the pressure relief sheet is withdrawn are shown in Table 2. As you can see, the peak pressure was between 0.82 psi and 1.62psi, which met the design requirements.

The serial number	1	2	3	4	5	6				
Installation	Positive	Positive	Positive	Reverse	Reverse	Reverse				
Peak differential pressure										
/psi when sheet is	1.25	1.17	1.11	1.36	1.22	1.26				
withdrawn										

Table 2 Peak pressure when drawing sheet

In various social and economic problems, the probability distribution of many random variables follows the normal distribution [8-9]. The experimental data obtained in the experiment passed the K-S test method, and the pressure peak X when the pressure relief sheet is pulled out follows the normal distribution, so the probability density of random variable X can be considered as:

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$$f(x) = \frac{1}{0.08 \times \sqrt{2\pi}} e^{-\frac{1}{2 \times 0.08^2} (x - 1.23)^2}, -\infty \prec x \prec +\infty$$

It can be calculated that the probability of pressure peak between the interval (0.82, 1.62) when the pressure relief sheet is withdrawn is 0.9999, then the batch of pressure relief device is considered to meet the design requirements.

4. Conclusions

Through the experiment, the pressure relief process and peak pressure of the pressure relief sheet when drawing out of the typical cargo hold rapid pressure relief device are studied, and the statistical method is used to analyze whether the batch of pressure relief device meets the design requirements, and the following conclusions are obtained:

1) The time from peak pressure to complete pressure relief of cargo compartment rapid pressure relief device is basically the same.

2) The peak pressure of the rapid pressure relief device in the cargo compartment during pressure relief is between 0.82 psi and 1.62psi in the effective design range.

3) Based on the statistical analysis method, through the analysis of a small sample size, it can be found that all the pressure relief devices of this batch meet the design requirements.

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