Research Into The Failure By A Brake Accumulator of A Civil Aircraft to Release Pressure

Zhou Jia
COMAC Shanghai Aircraft Design & Research Institute, Commercial Aircraft Corporation of China, Ltd, Shanghai, China
zhoujia3@comac.cc

Abstract—This document, based on a specific type of aircraft, analyzes the incomplete pressure release by the brake accumulator when the brake pedal performs the brake during the flight test, identifies the root cause, as well as finding the final solution. It can be viewed as a significant guide in flight testing or airline operations.

1. Introduction
Aircraft braking system is the most critical part in its deceleration on the ground, which determines the safety of aircraft landing. The system plays an important role in take-off and landing stage. At present, hydraulic brake system is widely used in modern civil aircraft. When the two sets of hydraulic systems fail under the extreme working condition, the aircraft brake can only rely on the energy stored by the brake accumulator. Therefore, performance of the brake accumulator determines the braking effect under the extreme conditions [1]. In this paper we study the problem resulting from the brake accumulator’s inability to be continuously depressurized in the flight test. After comprehensive analysis into the fault phenomenon, the fundamental root cause was identified, and the optimal solution was given, in consideration of the actual situations. This discovery can also provide a reference for the development of other civil aircraft brake systems.

2. Research into the failure of pressure relief of a brake accumulator for a civil aircraft

2.1. Background
During a flight test of one type of civil aircraft. The brake pedal was in motion to depressurize both the inner and the outer brake accumulators. The two outer brake accumulators were successfully depressurized to the designed pressure around 560psi, while the two inner wheel brake accumulators around 800psi, and would not depressurize further, even after repeated attempts by the pedals.

2.2. Introduction of the brake accumulators
The brake system consists of an inner - outer brake architecture. 1# hydraulic system and inner brake accumulator provide pressure for inner wheel break, 2# hydraulic system and outer brake accumulator provide pressure for outer wheel break. Altogether there are 2 accumulators in the brake system [2]. Under normal conditions, the brake accumulator pressure is around 560 psi. Their function is to store and provide alternative pressure when hydraulic system pressure increases, and to provide emergency power in the case of engine failure or emergency braking during hydraulic system failure or when depressurized. In these conditions, the pressure is at a high level. When the plane parks indoors or brought into maintenance, we depressurize the brake accumulator for security reasons. In general, there are two ways...
to depressurize the brake accumulator (Figure 1). One is by repeatedly operating the Park Emergency Handle. The other is repeated trampling the brake pedal of the forward/co-pilot. The pressure should be around 560psi after both attempts [3].

Figure 1. Park Emergency Handle and Pedal position.

2.3. Introduction of Park Emergency principle

The Park Emergency Handle depressurization system is shown in Figure 2. Pull the handle to trigger the Dual Park Emergency Valve, high-pressure hydraulic oil in the brake accumulator goes through the Dual Park Emergency Valve, Shuttle Valve, Hydraulic Fuse and other hydraulic components to brake the wheel, and the brake accumulator pressure is also reduced accordingly. Under normal circumstances, brake accumulator can provide at least 6 hours of park brake.

Figure 2. Emergency brake system schematic diagram.

2.4. Introduction of Pedal brake principle

The pedal braking system functions as shown in Figure 3, when using the brake pedal to depressurize, the pedal displacement sensor converts mechanical signal to current signal when the brake pedal is in motion. BCU (Brake Control Unit) receives the signal and triggers the shut-off valve on the brake, following which the hydraulic circuit is switched on. Eventually the brake pressure is put on by the signal of the Dual Brake Control Module.

Figure 3. Pedal signal transmission and control logic.

The schematic diagram of the aircraft brake pedal system is shown in Figure 4. When hydraulic system is switched off, the braking system relies solely on the brake accumulator to provide brake pressure. When the brake pedal is in operation, the hydraulic oil in the brake accumulator goes through brake shut-
off valve, brake valve, conversion valve, hydraulic pressure safety switch, hydraulic pressure sensor, etc. enabling the inner and outer wheel braking into effect. Concurrently the pressure from the brake accumulator is also released.

In the scenario of a hydraulic system failure, brake pedal system can still be used, however, the automatic anti-skid function have been disabled. When the brake pedal system is in operation, the hydraulic oil has to pass through the shut-off valve and brake value. Due to the high level of depressurization, the pressure drop of the accumulator will be relatively rapid when brake pedal is used, which demands the pilot to adopt inching on the brake pedal to avoid the rapid release of the pressure in the accumulator.

Figure 4. Pedal brake system schematic diagram.

3. Analysis

3.1. FTA (Fault Tree Analysis)

The FTA (Fault Tree Analysis) of the problem showing the external wheel brake accumulator can’t be continuously depressurized by using pedal. (Figure 5)

Figure 5. Failure analysis diagram.

3.2. Analysis of hydraulic system Display fault

In the test, use electric hydraulic pump was used to pressurize the brake accumulator, the increase rate of the pressure in the inner and outer brake accumulators was the same and both of them could reach 3000psi. When the electric hydraulic pump was turned off and the brake pedal was operated repeatedly, the
pressure drop in the inner and outer brake accumulators were almost at the same rate before it reached 800psi. When pressure of the inner and outer brake accumulator dropped to 800psi, the pedal brake could only reduce the pressure of the inner brake accumulator to 560±10 psi, and that in the outer brake accumulator could not continue to decrease. The outer wheel brake accumulator could only be depressurized to 560±10 psi by using the stop/emergency brake handle at the same time. To sum up, the problem was not a hydraulic system pressure display fault.

3.3. Analysis of BCU (Brake Control Unit) fault
When using pedal brake to depressurize the outer wheel brake accumulator, the pressure can drop from about 3000psi to about 800psi. It can be concluded that when the system pressure is greater than 800psi, the brake system can work properly. BCU can command the braking performance as desired. Since BCU (Brake Control Unit) is an electronic component, it will not be affected by the pressure of the hydraulic system. Moreover, the fault remained even after BCU was replaced, indicating that the fault was not affected by BCU. Therefore, it can be judged that this problem was not caused by BCU.

3.4. Analysis of wiring fault
The diagnosis into the wiring across the board was performed and it concluded that there was no alarm related to the brake system, apart from the alarm for emergency and maintenance. The braking system functions normally when the system pressure is greater than 800psi. It can be judged that this problem is not caused by the line fault from the brake system wiring.

3.5. Analysis of hydraulic components fault
There are two ways to depressurize the accumulator after analysis of the braking system, the pressure release in brake pedal and Park Emergency Handle were compared. We could dismiss any fault suspected in the hydraulic components built in the park and emergency handle. The ultimate difference between the two ways of braking comes down to the choice of the brake shut-off valve or the brake control valve.

3.5.1 Shut-Off Valve: shut-off valve is divided into two control valve: solenoid valve and pressure valve as in Figure 6. The solenoid valve controlled by BCU (Brake Control Unit), which shuts off the solenoid valve when receiving signal from brake pedal. When solenoid valve is switched on, the hydraulic oil reaches the pressure valve, as the pressure increases the high press opens the pressure valve. At this time the main brake shut-off valve is turned on and the main hydraulic oil lines are filled with hydraulic oil. The solenoid valve inside the brake valve is controlled by BCU (Brake Control Unit), and is not affected by the pressure of the hydraulic system, which can eliminate the fault of the solenoid valve inside the break valve, however, the turning on and off of the pressure valve inside the shut-off valve is greatly affected by the hydraulic system pressure. When the oil pressure is greater than the spring opening force of the pressure valve in the shut-off valve, the pressure valve turns on; when the oil pressure is less than the spring opening force of the pressure valve, the pressure valve turns off. At this point, the main oil line to the shut-off valve is closed, that indicates the brake shut-off valve is in a disabled state.

3.5.2 Dual Brake Control Module: The Dual Brake Control Module is internally divided into two identical solenoid valves, as in Figure 7, which respectively control thouter (or inner) left and right two wheels. After BCU (Brake Control Unit) receives the brake signal from the pedal, it controls the actions
of the two solenoid valves in the Dual Brake Control Module, and activates the main hydraulic oil circuit. The solenoid valve inside the Dual Brake Control Module is controlled by BCU (Brake Control Unit), not affected by the pressure of the hydraulic system, which can eliminate the failure of the Dual Brake Control Module.

Figure 7. Dual Brake Control Module schematic diagram.

Based on analysis above, when the system pressure drops to around 800 psi, the pressure valve in the outer brake cut-off valve is closed. At this point, the system pressure is not high enough to overcome spring open force, causing the pressure valve close and the main lines in the outer wheel brake shut off valve close. At this time, the accumulator pressure in the outer wheel brake is maintained at around 800psi that is the system pressure, when the shut-off valve is closed. To determine the root cause, the fault was caused by the opening force of the pressure valve inside the outer brake shut-off valve.

4. Validation test
After interchanging the two inner wheel shut-off brake valves the two outer wheel shut-off brake valves, the fault transferred. The problem of halted depressurization in the original inner wheel accumulator transferred to the outer wheel accumulator. After replacing two shut-off valves, the accumulator can continuously depressurize and meet the requirements. This test proved that the previous identification of the root cause was accurate.

5. In-depth Study
Through analysis and comparison of several brake shut-off valve parts, we found the opening forces of internal pressure valves were different, with opening pressure in the 367-1468psi range. As the valve opening force is mainly affected by the friction of the valve core, the friction force cannot be accurately controlled due to this characteristic. So the big difference in the opening forces of the valves was expected. Furthermore, increasing the requirements of the valve opening force will greatly increase the processing cost of parts. 25 finished products of shut-off valves were randomly selected and tested. The opening force for all 25 valves were different ranging from 520psi to 1510psi, among which 19 parts with the opening pressure exceeding 800psi (see Table 1)

| Serial No. | Shut-Off Valve Minimum operating pressure(psi) | Unit |
|-----------|-----------------------------------------------|------|
| 1         | 1510                                          | psi  |
| 2         | 1040                                          | psi  |
| 3         | 1310                                          | psi  |
| 4         | 1100                                          | psi  |
| 5         | 580                                           | psi  |
| 6         | 800                                           | psi  |
| 7         | 750                                           | psi  |
| 8         | 550                                           | psi  |
| 9         | 1250                                          | psi  |
| 10        | 700                                           | psi  |
| 11        | 1020                                          | psi  |
As the normal pressure supplied by hydraulic system is 3000 psi, there is no failure to open the brake shut-off valve, thus not affecting the normal function of the brake system. This problem only occurs when the hydraulic system is turned off to depressurize the brake accumulator. It is recommended to use the Park Emergency Handle to depressurize the accumulator. This operation does not affect the function of the brake system.

6. SUMMARY
In this paper, by analyzing various parts involved in the braking system of this particular airplane, we were able to identify the root cause for the problem, that is, the brake pedal was unable to depressurize the brake accumulator and propose potential solution. By comparing the cost and complexity of different solutions, the optimal solution was given.

References
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