Pressure Compensation Method of Check Valve in Aircraft Hydraulic System Based on Artificial Intelligence

L. I. Yaping(✉) and Q. U. Mingfei

College of Aeronautical Engineering, Beijing Polytechnic, Beijing 100176, China
`liyaping_12345@163.com`

Abstract. In view of the poor application effect of the traditional valve pressure compensation method, this study designed an artificial intelligence-based pressure compensation method for one-way valve of aircraft hydraulic system. Based on the functional block diagram of aircraft hydraulic system, the pressure conflict of aircraft hydraulic system is judged and the feasibility of pressure compensation is analyzed. Based on this, in order to analyze the fault conditions, the unified modeling of multiple systems, including hydraulic energy system, integrated management control system and hydraulic user system, was completed based on Modelica. Then the supplementary design was completed by designing the pressure compensation model of aircraft one-way valve. The experimental results show that compared with the traditional method, the pressure compensation effect of the proposed method is better, and it has higher practical application value.

Keywords: Artificial intelligence technology · Aircraft hydraulic · Check valve · Pressure compensation

1 Introduction

With the continuous improvement of aviation design and manufacturing level, modern aircraft flight tasks and flight conditions are gradually diversified, which also puts forward higher requirements for aircraft power demand and safety. The power of aircraft hydraulic system also increases, and the structure of hydraulic system is becoming more and more complex [1].

The aircraft hydraulic system provides hydraulic energy for hydraulic users on the aircraft, such as main flight control, auxiliary flight control, landing gear retraction and retraction, wheel braking, front wheel turning and engine backstepping. In order to ensure the flight safety of aircraft, modern aircraft system usually adopts system redundancy design to increase the safety and reliability of aircraft operation.

The hydraulic system of civil airliner is composed of multiple sets of independent and backup hydraulic energy systems to provide hydraulic energy for hydraulic users. Each set of hydraulic system is composed of hydraulic energy system and its corresponding hydraulic users. At the same time, there is an integrated management controller to

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monitor and control the working state of the hydraulic system [2]. There will be some differences in the design and layout of the hydraulic system of different types of aircraft according to the passenger capacity and purpose of the aircraft.

The aircraft hydraulic system is closely related to flight control, landing gear, avionics and other systems. The process from scheme design to integrated development is very complex. It is necessary to comprehensively consider the influence of various aspects such as mechanical electrical hydraulic control, as well as the interaction with various systems [3]. In the design process of the hydraulic system, the traditional design method mainly carries out physical experiments through the ground hydraulic test platform, uses the system platform to carry out a large number of hydraulic component tests and ground whole machine tests, and then modifies the design scheme through the test data, iterates continuously, and finally completes the finalization of the scheme [4]. However, it is difficult to adjust parameters through this design method, and each test requires a lot of time, capital and technical resources, which leads to the increase in the cost of aircraft hydraulic system design and development, and the development cycle becomes longer. At the same time, failure conditions such as single failure and double failure cannot be evaluated at the initial stage of scheme design. Therefore, the use of digital functional prototype technology and computer simulation technology in the design and development of aircraft hydraulic system has a great advantage in reducing test workload, reducing research and development costs, and improving the efficiency of system research and development [5].

In recent decades, with the continuous advancement of digital functional prototype technology and multi-domain unified modeling and simulation technology, the use of simulation models to simulate and analyze aircraft hydraulic systems has been continuously applied in the design process of aircraft hydraulic system schemes. The aircraft hydraulic system is a system involving different disciplines such as mechanics, hydraulics, electrical and control. The simulation analysis of a single field or a single hydraulic user cannot comprehensively consider the mutual coupling relationship between the systems, and cannot analyze the simultaneous action of multiple hydraulic users on the hydraulic system. The impact of the system, and it is difficult to verify the impact of hydraulic user load changes on the hydraulic control logic [6]. With the continuous development of the multi-domain unified modeling language, the digital functional prototype technology of multi-domain unified modeling has been widely used in hydraulic, mechanical, electrical, control and other fields, and the complex synthesis of multi-domain systems by simulation designers. The product can carry out overall system design and analysis. Therefore, in the process of designing the aircraft hydraulic system scheme, it is of great engineering significance to construct the functional prototype of the aircraft hydraulic system based on the multi-domain unified modeling technology [7].

With the rapid development of artificial intelligence, based on the idea of bionics, it attempts to create an intelligent machine that can replace human work. At present, artificial intelligence technology has gradually matured in many industries. Among them, the support vector machine, a classic method in machine learning, realizes the two classification of data in a multi-dimensional space by creating a hyperplane. It can reasonably use the two classification capabilities of the support vector machine in machine learning, that is, over. The idea of categorizing the ADs-B data of the two aircraft realizes the detection of flight conflicts. This method is also a classic in the pattern recognition method. As the most widely used neural network in the field of artificial intelligence, it has a working principle that is more in line with human brain thinking, memory and other behaviors. Therefore, it has more powerful potential for decision-making, recognition and learning issues [8]. In the traditional flight conflict detection, the model pays more attention to whether the flight conflict occurs, but rarely pays attention to the severity of the flight conflict and the future occurrence time, and the classification ability of the neural network can be used to make short-term predictions of the time of the flight conflict. For decision-making problems such as giving flight conflicts to resolve solutions, the neural network has shown its ability to quickly determine, and a reasonable design classification model for the problem can provide a solution for the two aircraft at the same time as the flight conflict occurs.

2 Method Design

2.1 Detect the Pressure Conflict of the Aircraft Hydraulic System

Aircraft hydraulic system is generally composed of hydraulic energy system, integrated management control system and hydraulic user system. The hydraulic energy system provides hydraulic energy for hydraulic users according to the control signals of cockpit and integrated management control system, and the integrated management control system controls the main components of hydraulic energy system according to aircraft status signals and hydraulic status signals, The hydraulic user completes the corresponding flight function driven by the control command and hydraulic energy [9].

The aircraft hydraulic system is also equipped with a hydraulic integrated management controller that can automatically control the main hydraulic components. During the working process of the aircraft hydraulic system, HIMC will continuously collect the working status signal of the hydraulic system, and receive the aircraft flight status signal at the same time, make judgments through the hydraulic control logic in the HIMC, and analyze the current flow pressure demand and failure conditions of the hydraulic system, so as to follow The flow requirements of different flight profiles of hydraulic users automatically turn on or off hydraulic electric pumps or PTUs.

The hydraulic user system mainly includes: aileron, elevator, rudder and spoiler actuation system, landing gear retractable system, front wheel turning hydraulic system and wheel brake hydraulic system and other 7 sub-systems. The hydraulic user receives the maneuvering instructions, and is driven by the hydraulic to realize the control of the flight attitude and the related maneuvering of the landing gear. The aircraft hydraulic system involves multiple fields such as hydraulics, machinery, control, etc.

The mutual coupling between each system must be considered comprehensively when designing the system. Its functional block diagram is shown in Fig. 1.

As shown in Fig. 1, the hydraulic energy system is one of the important energy systems on the aircraft, which mainly provides corresponding hydraulic energy for the hydraulic users on the aircraft. The aircraft hydraulic energy system is composed of 3 sets of mutually independent hydraulic energy systems, which are respectively connected

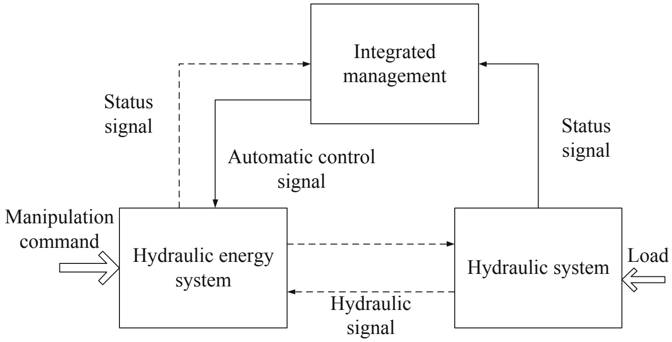

Fig. 1. Functional block diagram of aircraft hydraulic system

with the corresponding hydraulic users to realize the reasonable distribution of hydraulic load, and ensure that the pilot can still control the aircraft in the event of a single point of failure to achieve a safe landing of the aircraft.

2.2 Feasibility Analysis of Pressure Compensation

The system reliability needs to be analyzed before the system design, and the experimental data of the components that jointly constitute the aircraft system are calculated, which can respectively ensure the completeness of the aircraft hydraulic system design and serve as a reference for subsequent aircraft improvement. Functional reliability is the content that the aircraft hydraulic system needs to be analyzed in order to realize its function [10, 11].

This chapter analyzes the realization of pressure function, logic function and failure rate parameters of aircraft hydraulic system. The test platform is mainly used to simulate different pressure conditions of aircraft flight profile. Taking the aircraft flight process as the time axis, the aircraft from take-off to landing can be mainly divided into several stages: horizontal taxiing, take-off taxiing, rotary takeoff, take-off climbing, climbing, normal flight, aircraft descent, aircraft approach, landing flight, landing taxiing and aircraft taxiing. For different aircraft States, different pressure support is required under normal conditions, and the pressure requirements at each stage are shown in Table 1.

As shown in Table 1, the pressure required during takeoff is generally large, and the pressure is generally small during aircraft landing. In order to realize the above changes, necessary pressure simulation is needed to meet the signal requirements. The use of servo pressure control is not only a classic way of pressure control, but also a common method of aircraft hydraulic system. In order to realize this mode, the pressure and spool displacement are used as feedback in different states, and the pressure is controlled through PLC signal acquisition. Analog pressure load control is to realize the functional reliability of the aircraft. It is a semi physical simulation to simulate the pressure required by each hydraulic subsystem of the aircraft. It is an important premise to ensure the demand of the whole flight state of the aircraft. At the same time, it also meets the requirements of the aircraft hydraulic energy system for the pressure load simulation of each hydraulic user of the aircraft [12]. By analyzing different aircraft flight profile

Table 1. Definition of flight phase

Flight mission	Pressure demand (N/min)
Smooth line	7.84
Take off	81.36
Spin and lift off	82.68
Climb	82.78
Cruise	71.12
Decline	62.81
Go around	82.95

signals, the aircraft pressure demand can be divided into general step response and continuous change response. Different control parameters are used to simulate different pressure signals.

The load module is used to simulate the load pressure during aircraft flight and movement. Different pressure requirements need to be met for various stages and actions in the flight process of the aircraft. As the pressure simulation of actuator, on the one hand, the load simulation module needs to realize the mutual backup of the system and can be used. On the other hand, it needs to meet the given system pressure to carry out the actual simulation of the system. Pressure simulation using servo valve.

Since the oil pressure of the aircraft hydraulic system rises very quickly, in order to reduce the high temperature of the hydraulic system caused by the excessive temperature rise and reduce the system reliability, the back pressure valve is returned to the rear of the fuel tank and the logic is also required. Controlled temperature cooling control switch.

2.3 Design of Aircraft Check Valve Pressure Compensation Model Based on Artificial Intelligence

At present, most of the handling methods for flight conflict resolution rely on the manual operation of controllers and less use computer-aided system, which puts forward very high requirements for the ability and quality of personnel [13]. In route flight, especially in the complex airspace of the terminal area, it is difficult to carry out complex guidance for the aircraft. Therefore, the controllers usually formulate some command standards. Although the guidance for the aircraft is often not the optimal path, different controllers ensure the safe operation of the aircraft to the greatest extent through unified and standard command methods.

In the process of controller's command, the command command of guiding the aircraft is more intuitive, and the methods of adjusting altitude, speed and heading are often used to solve the flight conflict. Adjusting the vertical distance between aircraft is an important method to solve flight conflicts. Through height adjustment, flight conflicts due to the vertical distance less than the safety interval can be adjusted, and flight conflicts on the horizontal plane can also be solved in three-dimensional space through space expansion. Moreover, in the process of approach control, due to the close horizontal distance between aircraft and the large turning radius of aircraft, the method of adjusting course to avoid flight conflict is difficult to achieve, and it is relatively easy to change altitude. Therefore, the method of adjusting altitude is often used to solve the conflict.

In actual operation, it is important to pay attention to whether the adjacent altitude is occupied by other aircraft. If it is not occupied, the altitude adjustment method can be used. In addition, if there is a conflict between the ascending and descending aircraft altitude changes, the aircraft can first move to a conflict-free intermediate altitude, and then continue to ascend or descend after the conflict is resolved by related methods. When the cause of the conflict is that an aircraft is rising or falling and the distance between the aircraft is less than the safe interval, the conflict can be resolved by issuing an instruction to stop crossing. At the same time, for conflict resolution instructions, it is required to meet the one-step principle as much as possible to avoid the impact on other fluctuations caused by multiple changes in height. In order to reduce the pressure of aircraft hydraulic system, the pressure compensation model is constructed as follows:

$$B = HH^T \tag{1}$$

$$B' = D \wedge D^T \tag{2}$$

$$H_j^T = aD^T \tag{3}$$

$$a = H_j^T D \tag{4}$$

$$p = \sum_{i=1}^{k} \lambda_i \tag{5}$$

In formula (1–5), B is the symmetric positive definite matrix; B' is the decomposed symmetric positive definite matrix; H is the matrix of $m \times n$; T, a, and i are constants; D is the eigenvector; D^T is the T mutually orthogonal The characteristic vector of the point; H_j^T is the intelligent analysis vector of the j column of aircraft pressure; p is the contribution rate of aircraft pressure; k is the pressure characteristic value; λ_i is the characteristic principal component. This article standardizes the model data as follows:

$$X_i = \frac{X_i - X_{i\,\max}}{X_{i\,\max} - X_{i\,\min}} - 1 \tag{6}$$

In formula (6), X_i is the calibration value; $X_{i\,\max}$ and $X_{i\,\min}$ are the maximum and minimum values of calibration respectively. In this paper, let $p = 1$, then:

$$x_i = a_i f_1 + a_{i2} f_2 + \ldots + a_{iq} f_q \tag{7}$$

$$X = \begin{bmatrix} x_1 \\ x_2 \\ \cdots \\ x_i \end{bmatrix} \tag{8}$$

$$A = \begin{bmatrix} a_{11}\, a_{12} \ldots a_{1i} \\ a_{21}\, a_{22} \ldots a_{2i} \\ \ldots \ldots \ldots \ldots \\ a_{i1}\, a_{i2} \ldots a_{ip} \end{bmatrix} \tag{9}$$

$$X = AB + \varepsilon \tag{10}$$

In formula (7–10), x_i is the common factor; f_1, f_2, f_q, a_i, a_{i2}, a_{iq} are observable variables; X is the factor analysis formula; x_1, x_2, x_i are the pressure variables of the aircraft; A is the common factor pressure Load matrix; ε is the factor vector.

By constructing the model, the effect of pressure compensation needs to be further improved. The coupling relationship between various systems should be considered in the design process of aircraft hydraulic system. However, in the traditional modeling and simulation design, two methods are generally used. One is to establish a model of a single domain subsystem in a single software, fully analyze the subsystem, and then modify the system according to experience or test data to consider the impact of other systems. Its disadvantage is that the impact on other systems is not considered comprehensively and it is difficult to calculate accurately. The second is to model and simulate the aircraft hydraulic system through joint simulation [14]. This method first needs to artificially separate the coupling relationship between various systems, then establish simulation models in different software, integrate different models into one software through the interface between various simulation software, and build a joint simulation model to simulate the whole system. This method has high requirements for designers. They should master the operation of each software and be familiar with the interface between the software.

2.4 Realize the Pressure Compensation of the One-Way Valve of the Aircraft Hydraulic System

The design of the aircraft hydraulic system not only needs to consider the working characteristics of the hydraulic system under normal conditions, but also consider whether the hydraulic system can realize the function of energy system reconstruction under fault conditions. On the one hand, traditional design methods are difficult to analyze under fault conditions; on the other hand, the current modeling simulation does not model the system as a whole, and it is difficult to conduct a comprehensive analysis and evaluation of fault conditions.

A complete aircraft hydraulic system model, including hydraulic power system, integrated management control system and hydraulic user system, is required to analyze the failure conditions. Its structure is shown in Fig. 2.

In this study, the unified modeling of multiple systems is completed based on Modelica, which lays a foundation for the simulation analysis of fault conditions. Modelica is an open, object-oriented, equation-based computer language that can easily model complex physical systems across different domains, including: mechanical, electronic, power, hydraulic, thermal, control, and process-oriented subsystem models. The open Modelica standard library includes 920 component models from different physical domains with 620 functions.

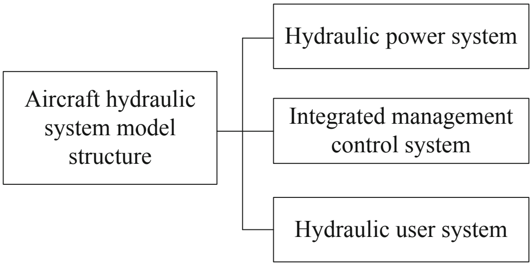

Fig. 2. Complete structure diagram of aircraft hydraulic system model

Due to aircraft hydraulic system of the power demand is bigger, strict in the volume and weight of the pump at the same time, as a result, the aircraft hydraulic system generally USES constant pressure variable piston pump as pump source, the constant pressure variable pump usually USES the axial plunger pump, axial type constant pressure variable piston pump with axial variable piston pump, the constant pressure valve and the variable cylinder.

Working principle of constant pressure variable pump: the setting pressure of constant pressure variable pump is determined by the preload spring of constant pressure valve. The setting pressure can be designed by changing the preload of spring. The pressure of the hydraulic system is determined by the load and regulated and limited by the constant pressure variable pump. When the system pressure is less than the set pressure, the constant pressure variable displacement pump outputs the maximum flow; When the system pressure reaches or exceeds the set pressure, the constant pressure variable pump enters the constant pressure model. In the constant pressure mode, the high-pressure hydraulic oil output by the pump controls the movement of the variable cylinder through the constant pressure valve. The change of piston displacement of the variable cylinder can change the inclination of the swashplate, so as to adjust the change of pump displacement. After the change of displacement, the output flow of the pump will also change, and finally achieve the adjustment of output pressure.

The control of the displacement of the constant pressure variable pump is the basis of constant pressure regulation. The displacement of the pump is controlled through the variable cylinder, so that the output flow of the pump is always consistent with the load flow demand, and the pressure of the regulating system is maintained near the working pressure.

The air-to-ground signal is used to determine whether the aircraft is in the air-flight state, and its high position indicates that the aircraft is in the air-state, including the aircraft's take-off, climb, cruise, approach, and preparation for landing stages. The signal is obtained by the pressure sensor installed on the landing gear struts of the aircraft. When the pressure of any sensor is not equal to zero, the wowC Weight On Wheels signal is true, and the aircraft is considered to be on the ground. The WOW signal is logically judged to produce the auxiliary signal of the aircraft hydraulic system, that is the air-to-ground signal. The air-to-ground signal is mainly judged by the control logic of the auxiliary hydraulic pump. Therefore, the actual working conditions of the aircraft hydraulic system must be considered comprehensively. Landing roll phase: When the

WOW signal changes from false to true, the aircraft hydraulic system is still in a high flow condition at this time, and the air-to-ground signal needs to be kept high for a period of time to ensure that the standby pump is turned on and the system has a large flow output; 2#hydraulic System low pressure condition: At this time, PTU needs to be turned on for pressure supply. If the aircraft is on the ground, PTU should not be turned on. When the above two conditions are met, the falling edge of the WOW signal is triggered, and the high bit remains for a period of time before it changes to the low bit.

The engine status signal is used to reflect the working status of the engine, including the aircraft's ground roll, take-off climb, cruise, approach and landing roll phases. The engine state signal can be generated by judging the positions of the left and right engine throttle levers. The engine signal is also the automatic control logic judgment of the user's standby pump. Therefore, the hydraulic system must be considered to meet the flow requirements of the hydraulic user in different working conditions.

In the ground idle phase: when the aircraft slides from landing to ground idle, the engine signal will change from true to false, but at this time, the hydraulic user is in the high flow condition, so it is necessary to keep the falling edge of the signal and delay the trigger for a period of time; Abort takeoff phase: when the aircraft needs to abort takeoff, the engine signal will change from true to false, but at this time, the hydraulic user is in high flow condition, so it is necessary to keep the falling edge of the signal and delay the trigger for a period of time. When the above two conditions are met, the falling edge of the engine status signal is triggered, and the high level remains for a period of time before it changes to the low level. The main function of the hydraulic pump control logic of the aircraft hydraulic system is to complete the energy reconstruction under the fault state of the redundant system. At the same time, it also has a certain function of energy optimal utilization, that is, it can automatically turn on or off the hydraulic electric pump according to the flow demand of the flight profile User system.

HIMC hydraulic pump control logic is composed of ACMP 1 B, ACMP2B, ACMP3A and ACMP3B control logic and PTU selection valve control logic_5. Due to the variety of control logics, the implementation and working principles of each pump control logic are the same. Therefore, the following mainly describes the automatic control logic modeling of the ACMPIB pump in detail, and the automatic control logic modeling process of other standby pumps is the same. The automatic control of the hydraulic pump is to automatically turn on the standby pump under high flow conditions and fault conditions, and automatically turn off the standby pump under low flow conditions and normal conditions. Large-flow operating conditions According to the principle of aircraft hydraulic system design, when the aircraft hydraulic system is in large-flow operating conditions and the No. 1 system is working normally, the electric pump ACMPIB acts as a backup pump to supplement the system's flow and stabilize the system pressure. When the aircraft is in the take-off or landing phase and the flap angle is not zero, the hydraulic system is in a high-flow condition. When the aircraft hydraulic system is in the normal flight profile, the system is under low pressure due to EDP 1. A failure, or the left engine is shut down. At this time, if the oil volume and oil temperature of the 1# fuel tank are normal, ACMPIB needs to be automatically turned on to supplement the pressure and flow of the system, To ensure the normal flight safety of the aircraft.

The electro-hydraulic servo valve is a key hydraulic component in the PCU. Its main function is to control the flow and flow rate of the hydraulic oil according to the electric control signal and the hydraulic servo signal, thereby controlling the extension or retraction of the actuator. The working principle is: when the control current is input, the control coil generates a deflection torque to make the jet tube deviate from the center position, the pressure in the two jet receiving tubes changes, the pressure on one side increases and the pressure on the other side decreases, so that the two ends of the main spool The pressure difference is generated, and the spool is driven to move relative to the valve body; meanwhile, the spool displacement generates a feedback torque through the feedback rod to make the jet tube return to the center position. When the torque generated by the control coil and the feedback torque are equal, the jet tube returns to the jet receiver. At this time, the main spool is in a stable position, and the corresponding flow and pressure control hydraulic oil are output.

3 Experiment and Analysis

In order to verify the practical effect of the one-way valve pressure compensation method of aircraft hydraulic system based on artificial intelligence, the following experimental process is designed.

3.1 Experimental Environment Parameter Design

In atmospheric air, even if the discharge voltage is up to 30 kV and the capacitor storage energy exceeds 4J, the test piece still cannot be ignited.

In the pure oxygen environment, as the pressure increases, the energy required to ignite the test piece decreases dramatically. Due to the limitation of test conditions, the pressure can only be raised to 3 Mpa in the experiment.

In the actual oxygenation process of the aircraft high-pressure oxygen check valve, the internal pressure of the valve can reach more than 10 Mpa, so it is estimated that the energy required for ignition is very small. In this environment, electrostatic discharge is easy to cause an explosion accident. In view of this situation, set the pressure parameters of the aircraft as shown in Table 2.

Table 2. Aircraft pressure parameters

Oxygen pressure/MPa	Falling pressure/MPa	Capacitors store energy/mJ
0.1	123.7	2808.45
0.5	113.4	897.80
1.0	105.0	12.00
2.0	92.1	48.05
3.0	81.2	7.20

In Table 2, the falling pressure of the aircraft will decrease with the increase of oxygen pressure. Therefore, the safety of the aircraft falling can be guaranteed to the maximum extent.

3.2 Experimental Results and Discussion

In the above experimental environment, the traditional method is compared with the method designed in this paper. The experimental results are as follows.

Table 3. Experimental results

Number of experiments/time	Compensation pressure by traditional method/MPa	Compensation pressure/MPa
1	121.2	251.3
2	134.5	278.2
3	142.3	302.4
4	156.8	327.9

According to the results shown in Table 3, the compensation pressure of the traditional method is small, which will lead to the problem of insufficient supply of aircraft hydraulic system, thus causing hidden trouble in flight. Compared with the traditional method, the pressure value compensated by the method in this paper is larger and always within the safety range, which proves that it can adapt to the supply effect of aircraft hydraulic system and meets the research purpose of this paper.

4 Conclusion

Although the probability of a large civil aircraft crash is low, it still exists. The analysis of the reliability of the aircraft hydraulic system can analyze the possible situations of the hydraulic system. Through prevention and key maintenance, the probability of aircraft crashes due to hydraulic system failures can be further reduced. The design of the hydraulic system test bench is an important process to ensure the successful development of the civil aircraft hydraulic system. It plays an important role in verifying whether the principle layout of the aircraft hydraulic system is reasonable and whether the various indicators meet the requirements. The necessary analysis can avoid unnecessary fatal errors in the aircraft development process.

In this paper, the necessary analysis is carried out in terms of reliability. Through the reliability analysis applicable to the general hydraulic system, the analysis is carried out with a focus on the failure rate parameters of the hydraulic system. The reliability of the aircraft hydraulic system should run through the entire aircraft design, not only the simulation settings of some reliability parameters need to be completed before the aircraft design, but also the reliability analysis of other parts during the aircraft installation process, until the aircraft completes the hydraulic system In the functional design of the above, it is necessary to collect various parameters of the aircraft during the final flight test phase and the normal operation phase of the aircraft, and reserve them for each aircraft maintenance use. This analysis is a general analysis and use case. Generally, it takes a long time to test the parts. This part of the design shows the parameters that need to be paid attention to for reliability, provides comparison and certain standards for the design of future civil aircraft, and improves the safety and professionalism of our civil aircraft.

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