Fault mode analysis and simulation verification of hydraulic system based on AMESim

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Abstract: This paper studies the relationship between the fault modes of hydraulic system and their flying parameters according to the principles of hydraulic systems. Based on the study of the working principle and composition architecture of the hydraulic system, the AMESim software is used to construct a simulation model of the hydraulic system, to analyse the fault modes and mechanisms of key components in the system and their failure effects, and to establish a link between the fault modes and the flying parameters according to which practical evaluation parameters are provided for the subsequent monitoring and handling of system failures.

1. Introduction  
AMESim (Advanced Modeling Environment for Simulation of engineering system) is a software for modelling, simulation and dynamics analysis of hydraulic and mechanical systems based on bonding diagrams from the French company Imagine. In order to further understand the impact of the failure of different components of the hydraulic system on the whole system, this paper will use AMESim software to simulate and analyse the main faults occurring in the hydraulic system of an aircraft type, and further understand the relationship between the flight parameters and the health status of the hydraulic system through simulation\textsuperscript{[1]}. In Section 2, the paper gives a detailed introduction to the composition of the hydraulic system of an aircraft and the working principle of the hydraulic system. Section 3 presents a simulation analysis of common fault modes in an aircraft failure report by means of constructing a simulation model. Section 4 summarises the simulation results, establishes the relationship between the flight parameters and the main fault modes of the hydraulic system, and obtains the actual evaluation parameters of the health status of the on-board hydraulic system. Section 5 provides a summary of the work in this paper.

2. Composition and working principle of hydraulic system  
The hydraulic system of a certain type of aircraft mainly consists of the main hydraulic system, the auxiliary hydraulic system (emergency hydraulic system) and the hydraulic indication system. The hydraulic system mainly provides the hydraulic source required for the work of landing gear retraction, flap retraction, front wheel turn manoeuvering and main landing gear wheel braking on the aircraft. The functional block diagram of the hydraulic system is shown in Figure 1.
3. AMEsim-based simulation of hydraulic system fault modes

3.1 Construction of the hydraulic simulation model

A simplified simulation of the landing gear and hydraulic system based on the structure of the hydraulic system is shown in the diagram below:

- 1-hydraulic oil tank; 2, 9, 11, 12, 18, 20-unidirectional valve; 3, 6-throttle valve; 4, 7-hydraulic pump; 5, 8-hydraulic motor; 10, 13-oil filter; 14, 22, 23-signal source; 15-relief valve; 16, 19-pressure accumulator; 17-2 bit 2 way hydraulic control valve; 21-3 bit 4 way hydraulic control valve; 24-unlocking actuator; 25, 27-spring-loaded hydraulic check valve; 26-hydraulic lock; 28-hydraulic lock; 29-one-way throttle valve; 30-landing gear actuator

When the aircraft engine is started, the engine torque drives two hydraulic pumps 4 and 7 to work to provide hydraulic pressure to its subsystem. When the aircraft takes off, the pilot puts the landing gear retract switch in the retracted position and the left end of solenoid valve 21 is energised; high pressure oil enters the rod chamber of the unlocking action cylinder 24 to push the piston to reset, and at the same time enters the rod chamber of the landing gear actuator cylinder 30 to retract the landing gear; the oil returned to the rodless chamber of the actuator cylinder passes through the hydraulic lock 26, check valve and solenoid valve to return to the oil tank in turn.
When the aircraft lands, the pilot will put the landing gear retract switch in the down position, so that the right end of solenoid valve 21 is energized; high pressure oil enters the rodless cavity of unlocking actuator cylinder 24, pushing the piston to the left to open the landing gear hook lock; after unlocking, the piston opens the high pressure oil circuit, and the oil enters the rodless cavity of landing gear retracting actuator cylinder 30 through hydraulic lock 26, pushing the piston to lower the landing gear; at the same time, the rodless cavity of landing gear actuating cylinder and the unlocking actuating cylinder returns to the oil tank through the solenoid valve, i.e. the return oil.

3.2 Left/right pump leakage fault simulation
In order to well simulate pump leakage failure to the hydraulic pump in parallel with a throttle valve, by setting the throttle valve different sizes of equivalent orifice diameter, can simulate the hydraulic pump occurs in different degrees of internal leakage situation. According to the system simulation model, the equivalent orifice diameters of different sizes of throttle valves are set to 0mm, 0.25mm, 0.45mm, 0.65mm and 1mm. The simulation simulates the effect of different degrees of pumps on the pressure of the main hydraulic system when leaking and on the effect of the actuating cylinder retraction time, the simulation time is set to 80s, and the complete landing gear retraction process is simulated by controlling the potential of the solenoid valve.
Figures 3 and 5 show that as the leakage from the left hydraulic pump gradually increases, the landing gear actuator cylinder displacement time gradually increases and the hydraulic system flow gradually decreases. Figures 4 and 6 then show that the left pump is unable to reach the pressure set by the hydraulic pump without driving the load due to a leak in the left pump, as well as a drop in the lowest point of the hydraulic pressure when driving the actuator barrel displacement.

3.3 Low Pressure Fault Simulation of Hydraulic Tank

The hydraulic tank pressurisation system is an important part of the on-board hydraulic system, its function is to ensure that in various flight conditions and flight altitudes, so that the tank can maintain the required residual pressure, the normal supply of oil to the system. The compressed air from the booster tanks is drawn from each engine pilot nozzle at a pressure of approximately 1.28Mpa (185.65psi), passing through a one-way valve, flowing to a filter drier to remove moisture and coarser impurities, then remaining to an air filter to remove fine impurities, then flowing to a pressure-reducing valve to reduce the pressure to 0.245MPa±0.01 MPa (35.53 psi±1.45 psi). 1.45 psi), and finally into the hydraulic oil tank for pressurisation.

The underpressurisation of the hydraulic tank is simulated by setting different pressurisation pressures of 2.45 bar, 2 bar, 1.5 bar, 1 bar and 0 bar. The simulation time is set to 80s and the complete landing gear retraction process is simulated by controlling the potential of the solenoid valve.
Fig. 7 Variation of displacement of the actuator cylinder with time for different pressurisation pressures

Figure 8 Variation of main hydraulic pressure with time for different boost pressures

Figure 9 Variation of hydraulic system flow rate with time for different boost pressures

Combined with the schematic diagram of the hydraulic system and the fault mode analysis it can be found that the boost pressure instability is often caused by poor suction caused by the ageing of the associated cylinder guard flaps. Combined with Figures 7, 8 and 9 it can be found that the impact of the boost pressure instability on the left/right pump is minimal, with a significant reduction in boost pressure eventually leading to a slight drop in main hydraulic pressure. Correspondingly, the effect on the landing gear retraction speed is minimal and the flow variation in the hydraulic system remains largely stable.

4. Analysis of simulation results

In addition to the above simulations, this paper also simulates a double pump low pressure alarm fault, a hydraulic pump output reduction fault caused by a hydraulic motor and a solenoid operated reversing valve control fault. In summary, the effects of different failure modes of key components in the main hydraulic system on the main hydraulic, hydraulic system flow and actuator cylinder displacement times are summarised in the table below.

Table 1 The main faults of the hydraulic system in relation to the flying parameters

| Component name | Fault manifestation | Influence on main hydraulic pressure | Influence on the displacement time of actuating cylinder | Influence on the flow rate of the main hydraulic system |
|----------------|---------------------|--------------------------------------|--------------------------------------------------------|--------------------------------------------------------|
| Left/right hydraulic pump | Left pump low pressure alarm | Extended time to reach scheduled pressure | Small increase in displacement time | Small reduction in flow rate |
| Left/right hydraulic pump | Low pressure alarm for double pumps | Inability to reach the intended pressure | Substantial increase in displacement time | Significant reduction in flow rate |
Hydraulic oil tank

| Low boost pressure alarm | Low impact | Low impact | Low impact |

Electromagnetic directional valves

| Control function failure | Extended time to reach predetermined pressure | Small increase in displacement time | Small reduction in flow rate |

Table 1 shows that when key components of the main hydraulic system fail, there are varying degrees of impact on the main hydraulic pressure, main hydraulic system flow, and actuator cylinder displacement time. Conversely, if these three parameters change, the health of the hydraulic system can be determined.

5. Conclusion
In this paper, firstly, the composition and working principle of the hydraulic system of an aircraft is studied. Then, a simulation model is constructed to analyse the common fault modes in the fault reports. The relationship between the flight parameters and the main fault modes of the hydraulic system is established through the simulation analysis, and the actual parameters that can reflect the real state of the hydraulic system are analysed on this basis, which facilitates the monitoring and handling of subsequent faults.

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