A CAS Message Simulation Module Used in Civil Aircraft for Air Management System Failure Diagnosis

Xi Haiyan
Shanghai Aircraft Design And Research Institute
Email: xihaiyan@comac.cc

Abstract. Air management system is one of the most important airborne systems on civil aircraft, which is responsible for controlling aircraft bleed air, cabin pressure control, wing anti-icing, cabin ventilation and temperature control. The air management control system is the brain and neural network of the entire air management system. The air management control system control the various subsystems of the air management system and control the air management system to work together with other interfaced systems. Air management system control logic and interface signals are the key points and most difficulty parts in air management system control. For this highly complex system, failure diagnosis is most important and difficult part in ground test and flight test. Usually faults are reflected on the CAS message and synoptic pages as the alarms. However, the causes of such alarms may be varied. The traditional trouble shooting approach is to check the control specification documents which are complicated and hard to find the root cause. If there is a CAS message simulation module database that can be quickly traced back to the trigger logic of any one of the alarms, and the signal relationship between the alarms is displayed, the control logic of the system is clearly displayed, the failure diagnosis would became simple and intuitive. Based on the above design intention with referring to control specification, this paper created a set of air management system alarm models by using Matlab/Simulink. These alarm models are used for system troubleshooting and design’s optimization. Finally, an application of cabin pressure control alarm with both trouble shooting and optimization is introduced.

1. Introduction
The size and complexity of embedded software in automotive systems has been increasing rapidly[1]. The air management system is one of the most important airborne systems on a civil aircraft. It is responsible for controlling aircraft bleed air, cabin pressure control, wing anti-icing, cabin ventilation and temperature control. The air management control system control the whole air management system and coordinate the sub systems to work together. The control system is also responsible for communicating with other interfaced system. Therefore, to realize the above control functions, the air management control system is allocated several thousand requirements. For this high complex system, to analysis the system’s failures in the ground test or flight test is one of most important and difficult parts in civil aircraft design. Normally such faults are usually reflected on the CAS messages and synoptic pages. However, the causes of such alarms may be varied. The traditional trouble shooting approach is to check the control specification documents which thousands of pages which are
complicated and hard to find the root cause. If there is a CAS message simulation module database that can be quickly traced back to the trigger logic of any one of the alarms, and the signal relationship between the alarms is displayed, the control logic of the system is clearly displayed, the failure diagnosis would became simple and intuitive. Based on the above design intention with referring to control specification, this paper creates a set of air management system alarm models and uses this model for the trouble shooting and system’s optimization.

2. CAS Message Model Design Strategy

2.1. System architecture
There is also a greater need to handle system-level control strategies, via communication networks and command software[2]. The Air Management System Integrated Control System is typically equipped with two Integrated Air Management System Controllers (IASCs), each containing two control channels (channel A and B) and one safety channel (channel S). For different system control requirements, different backups are used between the control channels to ensure that when one control channel fails, the other control channel still has full control capability. The safety channel is used to monitor and protect the functions of the system with high security.

2.2. CAS message model
According to the air management system control logic of a civil aircraft, and refer to[3][4], based on MATLAB/Simulink R2016, a set of air management system alarm model is created by using Simulink function. The model takes the civil aircraft air management system related controlled equipment, sensors and external signals as input. Based on the control logic described in the control specification, the result of directly triggering the CAS message is the output.

Take a FAULT alarm with bleed air failure as an example to introduce a model construction process. The ventilating failure FAULT alarm, the source of the fault includes temperature anomaly, pressure anomaly, equipment anomaly and sensor anomaly. The models are shown in Figure 1:

![Figure 1. Bleed air system alarm model](image)
3. Application

3.1. Failure Description

The air bleed system starts up through the APU bleed air when the aircraft is on the ground, and the cabin pressure control system uses the automatic mode. In the case of single PACK mode, the cabin pressure increased abnormally, and the CABIN PRESSURE DEGRADED alarm message appears. At the same time, we check the two outflow valve states that when the double PACK is closed, the outflow valve 1 is opened, the outflow valve 2 is closed, and the cockpit and cabin pressure are normal; after the APU started up, when the one-side PACK is opened, the outflow valve 1 is adjusted from the full open position to the full closed position, and the outflow valve 2 is kept closed. The outflow valve 1 is shown in figure 2 and the outflow valve 2 is shown in figure 3.

Figure 2. Outflow Valve 1

Figure 3. Outflow Valve 2

3.2. Failure Diagnosis

Basing the model on test data could be problematic when testing becomes impractical with many years of lifetime tests[5]. After analyzing the alarm simulation model, it can be found that the alarm of cabin pressure degraded, which is triggered by the failure of the outflow valve 2’s automatic control, and the cabin pressure degraded logic module is shown in Figure 4.

Figure 4. Logic module of cabin pressure degraded

There are three failure conditions for the outflow valve 2’s automatic control failure. The first is the outflow valve 2’s internal failure, the second is the command failure from the controller to outflow valve 2, and the third one is the communication failure between controller and the outflow valve 2. These three failure conditions are shown in Figure 5.
Figure 5. Logic module of outflow valve automatic control failure

From Figure 5, it can be seen that the alarm model can quickly analyze the potential fault source and locate the fault signal. By using failure logic module, all 21 potential fault sources can be easily sorted. To check each signal’s correctness is the trouble shooting solution. Finally, we found the root cause of the outflow valve 2 auto mode fault is the item 9 in figure 6, enable command failure. One port of item 9’s connector is out of connection, after fixing the connection, the outflow valve 2 works under the control.

3.3. Logic optimization

In this civil aircraft, the cabin pressure control system has two control valves, outflow valve 1 and outflow valve 2, when one outflow valve is working, the other one is stand-by.

In current design logic, in the case where the double PACK worked, the outflow valve 1 is normally opened, the outflow valve 2 is closed, the cockpit and cabin pressure are normal, while if the outflow valve 1 is failed, the outflow valve 2 will take over. but in the case where the single PACK automatic mode, the outflow valve 2 need to be worked and the outflow valve 1 is closed, but in case of outflow valve 2 is failed, the outflow valve 1 will not take over. Both of outflow valves closed position causes abnormal pressure in the cabin, and there is no FAULT CAS message to inform the pilot.

The current design logic may cause to this single point of failure, and it needs to be optimized. By compared with current cabin pressure alarm module, the optimization is shown in table 1.

Table 1. Optimization of outflow valve automatic control failure alarm

| CAS message | Before Optimization | After Optimization |
|-------------|---------------------|-------------------|
| FAULT       | The Cabin Press Fault CAS message will be triggered when the following three items are gathered  
1. The outflow valve 1 drive failure or exhaust valve 1 pressure sensor is disagree;  
2. The outflow valve 2 drive fails or the outflow valve 2 pressure sensor is disagree;  
3. Manual mode is not activated. | The optimization increases control channel’s and single pack mode’s identification.  
1. If 1A channel which control the outflow valve 2 works, then see if it is a single PACK. If both are yes, confirm whether this channel is invalid. If it’s invalid, and the system is in the automatic mode, it will report FAULT;  
2. If the control is not in the 1A channel, then see if it is a single |
| CAS message | Before Optimization | After Optimization |
|-------------|---------------------|--------------------|
| PACK, and if so, confirm whether the opposite channel is invalid, if it fails, and the system is in the automatic mode, it will report FAULT; 3.If the system is not in single PACK mode, it still uses the previous decision logic. |

DEGRADED  The Cabin Press Degraded CAS message will be triggered if outflow valve 1 drive failure or outflow valve 1 pressure sensor is disagree or outflow valve 2 drive failure or outflow valve 2 pressure sensor is disagree. Keep original design. Because when the FAULT message is triggered, the Degraded message will be inhibited automatically.

The logic of the cabin pressure failure alarm before optimization is shown in Figure 6:

![Figure 6. Logic module of cabin pressure fault alarm](image)

Considering the optimization mentioned in table 1, the modified cabin pressure fault alarm increases the consideration the both single PACK mode and channel’s identification. The optimized alarm logic is shown in Figure 7:

![Figure 7. Optimized logic module of cabin pressure fault alarm](image)

After the logic modification is completed, we have tested the failure test for three different working conditions. The test results are shown in Table 2:
Table 2. Verification results for cabin pressure failure alarm’s optimization

| Failure mode                                                                 | Output before | Output after |
|------------------------------------------------------------------------------|---------------|--------------|
| 1A channel control, single PACK mode; At this time, the outflow valve 2 is disabled. | ![Graph](image1.png) | ![Graph](image2.png) |
| 2A channel control, single PACK mode; At this time, the outflow valve 2 is disabled. | ![Graph](image3.png) | ![Graph](image4.png) |
| Not in single PACK mode, the outflow valve 2 is disabled.                     | ![Graph](image5.png) | ![Graph](image6.png) |

Note: When oscilloscope’s output equals 0, it means not failure; When oscilloscope’s output equals 1, it means failure.

Through the oscilloscope output, it can be seen that in order to verify the validity of the model, first test case is the 1A channel control, the single PACK automatic mode, and the failure of the outflow valve 2 at this time, the left picture shows the oscilloscope when the model is not modified. The output result shows that the output value is 0, that is, the system does not report FAULT; the right picture shows the output of the oscilloscope after the model is optimized. It can be seen that after a 50ms pulse, the output value is 1, that is, the system reports FAULT message according to the optimized requirements. The second case is the 2A channel control and other conditions the same as the first case, we get the same results. Finally, we cancel the single PACK mode. At this time, the outflow valve 2 is invalid. It can be seen that the modified logic is consistent with the report result of the logic before the optimization which is just our expectation. that is, it is a report, which is in line with our design expectations.

4. Summary
This paper first introduces the air management system and its high complexity. Then a developed simulink-based alarm model for the air management system function is introduced. Based on this alarm model, the paper analyzes and locates the single PACK mode failure fault of the cabin pressure control system by using the alarm model. With the support of the model, the fault is solved. After further analysis of this fault and current design logic, it is confirmed that the current logic needs
further optimization. Finally, the paper analyzes the valve control logic of the cabin pressure control system in detail, and clarifies the optimization direction. Based on the existing logic, the failure judgment of the single PACK mode is considered, and the optimized logic improves the reliability of the system.

References
[1] Srihari Sukumaran, 2011, Applying Software Dependence Analysis for Automotive Embedded Software Andersen, SAE International
[2] Allen, J., 2012, Simulation and Test systems for validation of Electric Drive and Battery Management Systems, SAE International
[3] Wu, Luochang, 2012, On monitoring and testing system of the hydropower unit vibration based on virtual instrument technology, ICMST 2011
[4] Ma You-Jie, 2011, Simulation and parameters tuning of second order ADRC controller in SIMULINK, ICMST 2011
[5] Nabil Mohammed Hammad, 2010, Vehicle Valve Regulated Lead Acid Battery Modeling and Fault Diagnosis, SAE International