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ANALYSIS AND SOLUTION RESEARCH OF THE AIR DATA LOSS FROM AIRCRAFT FOR ENGINE CONTROL

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Abstract

Engine control system needs to receive important data from other aircraft subsystem to output the required thrust and power of aircraft according to engine control logic, such as aircraft air data, thrust level angle, bleed configuration and so on. This paper analyzes the impact on aircraft safety and performance, which due to engine control system lost the main air data from aircraft. Also, a traditional solution of air data loss is presented. Finally, the paper describs a more optimization design solution based on studying engine power control logic.

Keywords: Engine; Air data; Total pressure; Static pressure

1. Introduction

The engine is the heart of the aircraft, not only to provide the aircraft with required thrust, but also the most importent power supplier for aircraft. Engine control system is the brain and central nervous system of engine, which control the normal operation and output the required thrust and power according to the current flight condition and aircraft command. If engine control system loses aircraft data, the engine will not work normally, affecting the normal flight safety. The aircraft should take action to ensure the normal flight safety.

In addition to providing thrust for the aircraft, the engine also provide air bleed, electrical power and hydraulic power to the aircraft. Under the normal flight conditions, the engine control system needs to receive signals from the aircraft subsystem, such as Weight on Wheels, approach idle, bleed configuration, air data, throttle level angle command, auto-throttle command, engine trim command, Thrust reverser status and engine itself signals from the engine sensors (such as rotor speed, vibration, oil temperature, etc.), calculated the engine idle reference or N1 command according to the adjustment law of fuel flow and engine control logic. Engine power management principle diagram as shown in the figure 1.

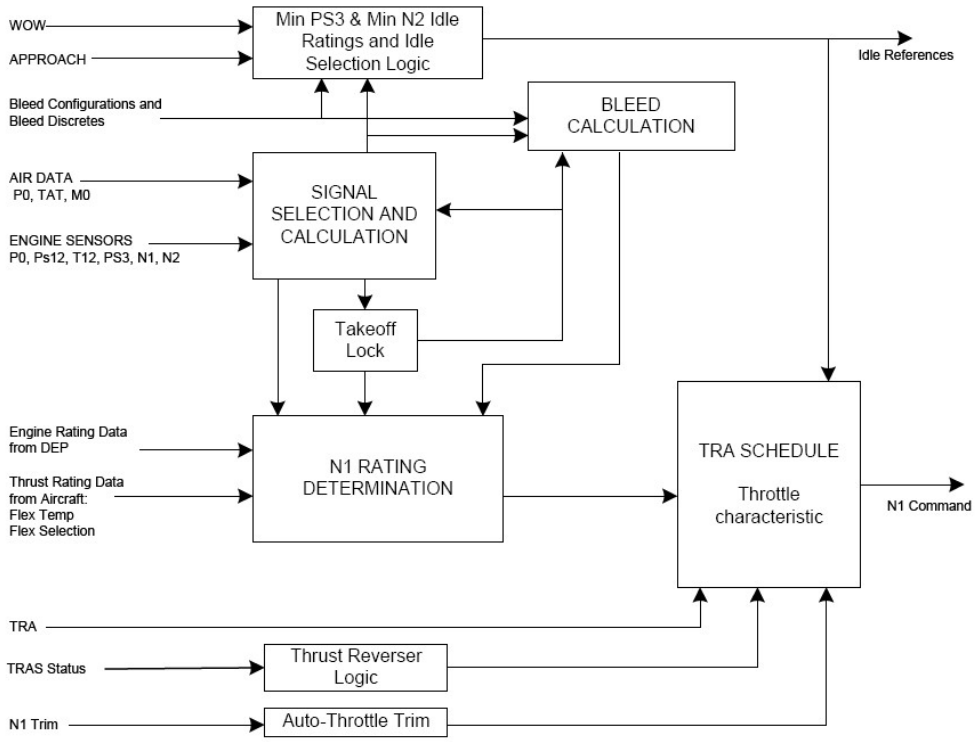

Figure 1 – Engine power management principle diagram.

The engine power is mainly divided into two parts, one is the aircraft extraction power, and the other is the engine thrust. The main influencing factors of aircraft power extraction are the electrical power requirement of aircraft electrical system and the hydraulic power requirement of aircraft hydraulic system, however the main factors that affect the thrust performance of the engine are aircraft altitude, speed, temperature, humidity, air bleed configuration and thrust level angle command. In the whole flight envelope, FADEC that is engine controller calculates the altitude, temperature and speed of the aircraft by receiving the total pressure, static pressure, total temperature, Mach number and other parameters of the aircraft, knowing the pilot's command by receiving Thrust level angle; calculating extraction power requirement by receiving the air bleed configuration. Based on the above aircraft input parameters, according to the engine control logic to calculate the engine correction speed N1. Aircraft altitude, temperature and speed parameters is calculated by the aircraft total pressure (PT2), static pressure (P0), total temperature (TAT), Mach number (M0) and so on. These aircraft parameters will directly impact on engine N1 and TATSEL calculated, so the aircraft air data PT2, P0, TAT, M0 is the key input parameters to the engine control system, as shown in figure 1.

2. Impact analysis of lost aircraft air data for the engine control system

Due to some aircraft faults, such as the physical interruption of the transmission data bus between the aircraft and the engine or the loss of air data source, FADEC will fail to receive the important air data from the aircraft normally, which will affect the engine thrust control and ultimately affect the flight safety and performance of the aircraft.

2.1 Principle diagram of aircraft air data

Aircraft air data system has two total temperature sensors, four static pressure sensors, two total pressure sensors and one full (left and right) static pressure sensors, separately installed on both sides of the aircraft nose and body, through the air data module (ADM) collects original air data from aircraft, after air data controller (ACE) processing, then the flight control module (FCM) of flight control computer will output 3 sets of selected air data to other aircraft subsystem for using in control logic, including 3 sets of total pressure, static pressure, total temperature and Mach number, as shown in figure 2.

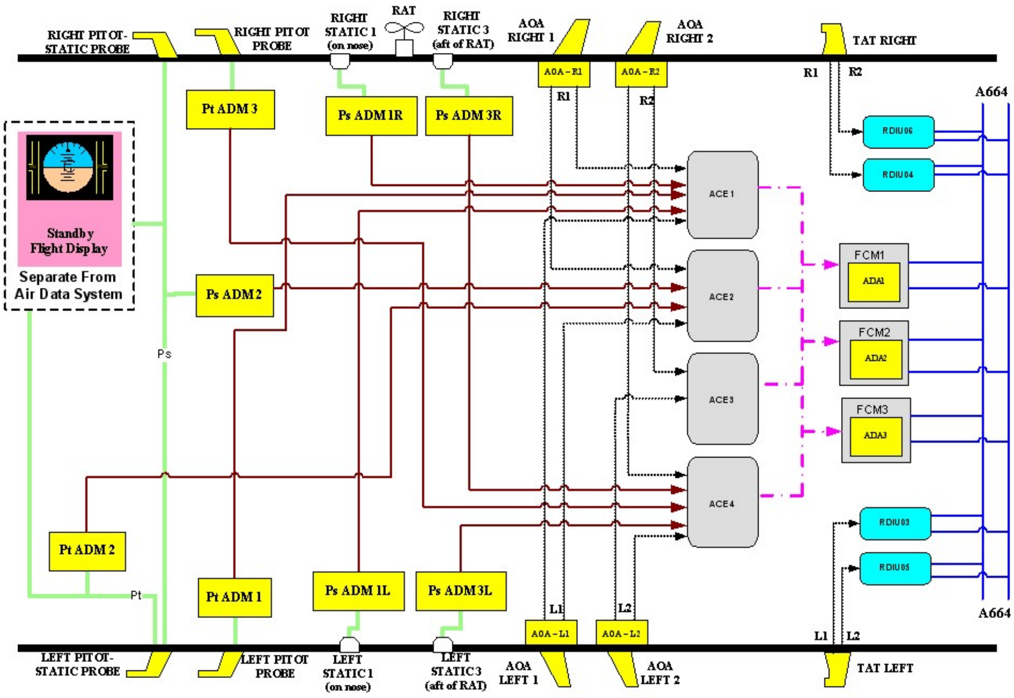

Figure 2 – Aircraft air data system principle diagram

The air data from the aircraft is used to calculate the N1 command and the total temperature TATSEL. Under normal flight conditions, FADEC uses PT2, P0 and TAT signals of the aircraft, plus corresponding sensor signals of the engine itself to calculate the Mach number and TATSEL of the aircraft, so as to calculate the modified rotor speed N1 required by thrust control. Specific functions of each aircraft data are described as follows:

(1) aircraft PT2: it is used for calculating aircraft Mach number M0;

(2) aircraft P0: it is used to calculate the altitude and Mach number M0 of the aircraft;

(3) aircraft TAT: it is used to calculate the correction factor of correction speed;

(4) aircraft M0: data backup for calculated M0.

2.2 Impact analysis of lost aircraft air data for the engine control system

If the air data source of the aircraft is lost or the received air data is unavailable, FADEC cannot know the current flight condition of the aircraft, including the aircraft altitude, the Mach number and the current total temperature. Without these key input parameters, FADEC cannot output the required thrust normally, which affects the flight safety and performance of the aircraft. Then, the engine will use its own sensor data to replace the sensor data of the aircraft to ensure the flight safety of the aircraft.

The engine itself has total temperature sensor T12 in fan import and static pressure P0 sensor in inlet import. FADEC only uses two P0 data sources of engine to calculate the P0SEL parameters to obtain aircraft altitude. FADEC only uses two T12 data sources of engine to calculate the TATSEL parameters to obtain the correction factor of correction speed N1. In the process of calculating PT2SEL parameters, all the data sources of the aircraft are lost, so the total pressure data of the aircraft cannot be obtained. Besides, the engine has no corresponding total pressure sensor, so FADEC cannot calculate the Mach number of the aircraft. The Mach number of the aircraft is the key parameter of the engine thrust control. Without the aircraft Mach number, the required thrust of the aircraft cannot be calculated, which affects the normal operation and flight safety of the aircraft. The Mach number of the aircraft is also calculated based on the total pressure PT2 of the aircraft and the static pressure P0. If the total pressure PT2 of the aircraft is lost, the Mach number of the aircraft will also be lost.

In summary, the loss of P0 and TAT signals of the aircraft will not have a significant impact on the normal operation of the engine, because the engine can calculate P0SEL and TATSEL by using its own sensors. However, if the total pressure PT2 signal of the aircraft is lost, FADEC cannot calculate the Mach number of the aircraft, and the engine control system cannot operation normally to output the aircraft required thrust, which will affect the normal operation and flight safety of the aircraft.

3. Aircraft air data loss fault solution

In order to ensure the normal operation and flight safety of the aircraft, the aircraft must resolve the loss failure of aircraft total pressure PT2 data.

3.1 A traditional solution -- engine alternate control mode

If the air data from the aircraft is lost, the engine control system cannot control the engine power output according to the normal control mode. In order to make the engine operation normally and ensure the flight safety of the aircraft, the engine will enter the alternate control mode. When the engine loses the air data of the aircraft and cannot work in the normal control mode, the flight crew or the engine control system itself can manually or automatically trigger the engine to enter the engine alternate control mode.

Engine control logic is different between the engine normal control mode and the engine alternate control mode, the engine alternate control mode is only use engine sensors and assuming model of engine control parameters, so the engine alternate control mode is the larger error power control mode and the engine thrust is inconsistent between left engine and right engine. The engine itself sensors mainly include the static pressure at the engine inlet import (P0) and the total fan import temperature (T12). The assumed Mach number model of the engine is used to estimate the Mach number of the aircraft. TATSEL is only calculated by using two engine sensors sources of T12, and the correction factor N1 is obtained, which calculated the main engine control parameter—— modified N1 speed. Since the calculated Mach number is based on the assumed Mach number model of the engine and the assumed Mach number model is based on assumed engine model, there is a certain error between the assumed Mach number and the real Mach number of the aircraft, so there is also a certain error in the modified speed N1 calculated based on the assumed Mach number. However, the thrust inconsistent caused by the Mach number will not affect the flight safety of the aircraft. According to the model calculation, the thrust difference between left and right engines is about +/ -6%.

The engine alternate control mode is a degraded mode of the engine. The main purpose is to ensure the flight safety of the aircraft and the engine, and then other factors such as aircraft economy will be considered. Therefore, the engine power output of the engine alternate control mode is not less than that of the engine normal control mode.

3.2 A better solution -- PS12 sensor added at engine fan inlet

If all three sets of total pressure PT2 data of the aircraft are lost or all are unavailable, FADEC can use the two static pressure sensors of the engine to calculate the Mach number M0 of the aircraft. The two static pressure sensors are inlet static pressure sensor and fan inlet static pressure sensor. In the existing pressure sensors of the engine, only the static pressure sensor P0 at the inlet port is available, so it is necessary to install an additional static pressure sensor at the engine fan inlet to measure the static pressure data PS12 at the fan inlet, as shown in figure 3.

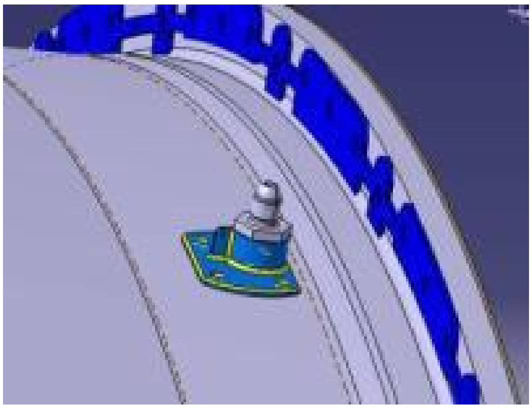

Figure 3 – The static pressure data PS12 at the fan inlet

FADEC USES two inlet static pressure P0 data sources to calculate and generate, together with the collected static pressure data of fan inlet, and takes the ratio as a variable parameter to calculate the aircraft according to formula 1, which is as follows:

$$PT2 = P0SEL * F(\frac{PS12}{P0SEL}, N1K12) \quad (1)$$

Where is the N1 correction speed based on the TATSEL standardization.

The neutralization relation in the above formula is one-to-one corresponding to the corrected speed, and the corresponding relation is a group of isobaric ratio curves calculated according to the real engine model, inlet characteristics and engine performance, as shown in figure 4. The isobaric curves are also modified based on powerplant performance test flight data (such as FTB test flight data) to improve the accuracy of the curves. When a correction speed is given, the corresponding value can be found according to the curve in figure 4. Is the static pressure at the inlet of the air inlet calculated by using the two data sources of the engine sensor, then FADEC can calculate the aircraft signal according to formula 1, and replace the lost aircraft signal with the calculated one.

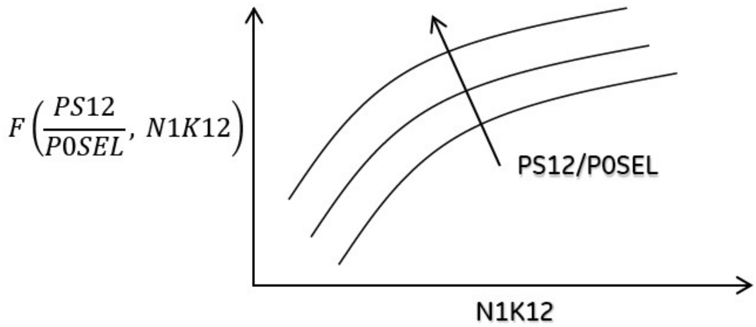

Figure 4 – $\frac{PS12}{P0SEL}$ curve

When FADEC is calculated, the Mach number M0 can be calculated according to formula 2, which is as follows:

$$M0 = \sqrt{\frac{2}{\gamma - 1}\left[\left(\frac{PT2}{P0SEL}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]} \quad (2)$$

Psi when both Psi and Psi are Psi. $\gamma = 1.4$

The PS12 hydrostatic sensor does not require the pilot to do anything if the engine loses atmospheric data, so there is no need to design the engine backup control mode switch in the cockpit. Under normal circumstances, FADEC will compare aircraft PT2 with PT2 calculated by PS12. If the difference between aircraft PT2 and PT2 calculated by FADEC exceeds a certain value, FADEC will automatically use its calculated PT2 to calculate the Mach number of the aircraft to participate in engine thrust control. If the difference value of PT2 calculated by the aircraft and FADEC is within the acceptable range, then FADEC will use the 3 PT2 data sources of the aircraft plus the 2 PT2 data sources calculated by the engine to conduct selection processing and calculate that PT2SEL participates in engine thrust control, which is similar to the calculation method of P0SEL and TATSEL. If missing aircraft air data engine, due to the engine mounted PS12 static pressure sensors, FADEC is automatically used engine fan import static PS12 PT2 calculation, and the calculation method of P0SEL and TATSEL similar, does not affect the engine thrust control, so that the pilot does not need to know engine air data lost, also do not need to take any protective measures, the plane can also ensure the flight safety and performance. In addition, the PS12 static pressure sensor can improve the control accuracy of the engine and reduce the inconsistent values of the left and right engine thrust. FADEC USES real-time sensor data to calculate the value of PT2, which is closer to the real aircraft PT2. Compared with the method of assuming the Mach number model, the accuracy is improved greatly. After the simulation calculation, the PS12 static pressure sensor will cause the difference in thrust between the left and right engines at +/ -3.5%.

4. Comparative analysis of advantages and disadvantages of solutions

Comparing the two schemes of backup control working mode and installing fan inlet static pressure PS12 sensor, the methods of installing PS12 sensor mainly have the following advantages and disadvantages:

(1) the thrust imbalance between the left and right engines is smaller, from +/ -6% to +/ -3.5%, which optimizes the aircraft performance and improves the dispatch rate;

(2) improve the control accuracy of engine thrust;

(3) it is not necessary to design a backup control mode switch in the cockpit;

(4) the failure of the engine to lose the aircraft's atmospheric data does not need the pilot to know;

(5) after the loss of atmospheric data of the aircraft engine, the pilot does not need to take any measures to reduce the burden on the pilot;

(6) the total weight of the engine has been increased, and the added sensors and related pipelines and cables are expected to add about 2.5kg weight to each engine.

Through the above comparative analysis, the C919 adopted a better solution -- adding a fan inlet static pressure PS12 sensor to solve the engine's failure of losing atmospheric data.

References

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