
Multiple system failures, Airbus A340-642, G-VATL

Micro-summary: FMC failures, engine failure, and a possible fuel leak affected this Airbus A340 flight and ended up in the declaration of a Mayday.

Event Date: 2005-02-08 at 0330 UTC

Investigative Body: Aircraft Accident Investigation Board (AAIB), United Kingdom

Investigative Body's Web Site: <http://www.aaib.dft.gov/uk/>

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INTERIM REPORT AND SAFETY RECOMMENDATIONS

Aircraft Type and Registration:	Airbus A340-642, G-VATL	
Manufacturer's Serial Number:	376	
No & Type of Engines:	4 Rolls-Royce Trent 556-61 turbofan engines	
Year of Manufacture:	2001	
Date & Time (UTC):	8 February 2005 at 0330 hrs	
Location:	En-route from Hong Kong to London Heathrow	
Type of Flight:	Public Transport (Passenger)	
Persons on Board:	Crew - 18	Passengers - 293
Injuries:	Crew - None	Passengers - None
Nature of Damage:	None	
Commander's Licence:	Airline Transport Pilot's Licence	
Commander's Age:	43 years	
Commander's Flying Experience:	7,000 hours (of which 3,100 were on type) Last 90 days -120 hours Last 28 days - 85 hours	
Information Source:	AAIB Field Investigation	

Synopsis

This report follows on from AAIB Special Bulletin S1 of 2005 which published the circumstances and facts established during the early part of the investigation. Investigative work continues and the final report will not be published before February 2006. This interim report contains safety recommendations addressed to the primary certification bodies for large transport category aircraft.

History of the flight

The flight was scheduled to depart Hong Kong at 1535 hrs (2335 local) on 7 February with a scheduled arrival time at London Heathrow of 0450 hrs the next day. There was one relevant entry in the technical log prior to departure; both Fuel Control Monitoring Computers (FCMCs) had

been reset at separate times on the previous sector. During the pre-flight preparation period for this flight there was one FCMC 2 and one FCMC 1 failure; the crew were able to carry out successful resets on each occasion.

The aircraft took off from Hong Kong at 1621 hrs. Shortly after takeoff there was an Electronic Centralised Aircraft Monitor (ECAM) alert advisory 'FCMC2 FAULT' displayed. There were no ECAM actions associated with this fault and the commander decided to delay any attempt at a computer reset until the aircraft had reached its cruising level. When the aircraft reached its initial cruise level the crew attempted an FCMC2 reset using the computer reset procedure in the Quick Reference

Handbook (QRH). The reset attempt was unsuccessful. There were no further fuel system warnings, cautions or messages throughout the remainder of the flight.

The aircraft was cruising at FL380 in Dutch airspace when, at 0330 hrs, No 1 engine lost power. The flight crew secured the engine and the commander decided not to attempt to relight it but to continue towards Heathrow on three engines. The flight crew noticed that the fuel contents for the inner 1 fuel tank, which feeds engine No 1, was reading zero. Suspecting a possible fuel leak, a flight crew member was sent aft to inspect the engine area from the passenger cabin but nothing unusual was seen. However, soon afterwards, the crew observed the No 4 engine power fluctuate and noticed that the inner 4 fuel tank was also indicating zero fuel contents. The commander opened all the fuel crossfeed valves and the No 4 engine recovered. A 'MAYDAY' was declared and a diversion to Amsterdam Schipol Airport was initiated.

When the diversion commenced the total fuel on board was in excess of 25,000 kg but there were significant quantities of fuel located in the trim, centre and outer wing fuel tanks. Manual fuel transfer was started by the flight crew but they did not see immediately the expected indications of fuel transfer on the ECAM. Consequently, the flight crew remained uncertain of the exact fuel status. The diversion to Amsterdam continued and the aircraft landed there without further technical problems.

Investigative work in progress

To assist in the understanding of the events that surrounded the incident, the fuel system computers fitted to G-VATL have been installed onto a development A340-600 which will allow close monitoring and recording of the fuel system operation during all phases of flight. This, coupled with other investigative actions, may help to determine the root cause of the incident. Also, a detailed examination is underway into the presentation of fuel

system data to the flight crew during a flight, especially following a FCMC failure, and also data used by the maintenance engineers for troubleshooting following a flight in which a fuel system anomaly was discovered.

Fuel system regulations

Large aeroplanes

A review of the current European EASA and US FAA regulations for large aeroplanes revealed that neither EASA CS-25 nor FAA FAR-25 contain a requirement for a low fuel level warning. The only specified requirement for fuel level is a fuel quantity indicator as quoted below:

CS 25.1305 Powerplant instruments

(a) For all aeroplanes

(2) A fuel quantity indicator for each fuel tank.

This basic requirement is amplified as follows:

'CS 25.1337 Powerplant instruments

(b) Fuel quantity indicator. There must be means to indicate to the flight-crew members, the quantity, in litres, (gallons), or equivalent units, of usable fuel in each tank during flight. In addition –

(1) Each fuel quantity indicator must be calibrated to read 'zero' during level flight when the quantity of fuel remaining in the tank is equal to the unusable fuel supply determined under CS-25.959;

(2) Tanks with interconnected outlets and airspaces may be treated as one tank and need not have separate indicators; and

(3) Each exposed sight gauge, used as a fuel quantity indicator, must be protected against damage...'

Despite this lack of a stated requirement for a low fuel level warning, EASA CS-25.1309 Equipment, systems and installations paragraph c) has a generic requirement for all aircraft systems, including fuel, which states:

“Information concerning unsafe operating conditions must be provided to the crew to enable them to take appropriate corrective action. A warning indication must be provided if immediate corrective action is required. Systems and controls, including indications and annunciations must be designed to minimise crew errors, which could create additional hazards.”

Normal, Utility, Aerobatic, and Commuter Category Aeroplanes

A review of similar regulations for other aircraft and rotorcraft reveals that there is a requirement for a low fuel level warning on some aircraft. The requirement is contained in EASA CS-23 Certification Specifications for Normal, Utility, Aerobatic, and Commuter Category Aeroplanes:

*‘CS-23.1305 Powerplant instruments...
... (c) For turbine engine-powered aeroplanes
In addition to the powerplant instruments required by sub-paragraph (a), the following powerplant instruments are required:*

- (1) A gas temperature indicator for each engine.*
- (2) A fuel flowmeter indicator for each engine.*
- (3) A fuel low pressure warning means for each engine.*
- (4) A fuel low level warning means for any fuel tank that should not be depleted of fuel in normal operations...’*

Small Rotorcraft

The EASA CS-27 Certification Specifications for Small Rotorcraft state:

*‘CS-27.1305 Powerplant instruments
... (l) A low fuel warning device for each fuel tank which feeds an engine. This device must:*

- (1) Provide a warning to the flight crew when approximately 10 minutes of usable fuel remains in the tank; and*
- (2) Be independent of the normal fuel quantity indicating system...’*

Large Rotorcraft

The EASA CS-29 Certification Specifications for Large Rotorcraft state:

*‘CS-29.1305 Power plant instruments
... (4) A low fuel warning device for each fuel tank which feeds an engine. This device must:*

- (i) Provide a warning to the crew when approximately 10 minutes of usable fuel remains in the tank; and*
- (ii) Be independent of the normal fuel quantity indicating system...’*

The FAA regulations FAR-23, 27 and 29 are similar to the EASA regulations above.

Discussion

Large aircraft, especially those equipped with glass cockpits and computerised management systems, are very complex and to that end the flight crew have to rely on the aircraft’s systems warning them of problems. Although a low fuel level in the engine feeding fuel tanks should normally never occur (when the system is operating correctly) this investigation has shown that

when the system fails to operate correctly and if the crew are not aware of the situation, they are unable to act in an appropriate manner and prevent engine fuel starvation. It could be argued that the need to indicate fuel system failures to the crew on complex aircraft is covered by EASA CS-25 1309 paragraph c. Indeed, when the fuel control system is operating normally on the A340-600 this is true, but this incident demonstrated a need for more specific requirements for certain warnings such as low fuel level in an engine feeder tank.

Another argument for not having the requirement for a low level fuel warning could be that aircraft certified to EASA CS-25 are operated by a minimum of two flight crew and therefore at least one of these would be monitoring the fuel status. However, the flight crew have to monitor several systems at once placing more reliance on warning systems and flags to identify an impending problem. Also, with the larger aircraft, the fuel system may be used for centre of gravity control. Fuel tank feeding sequences may be complicated and some fuel tanks may be depleted and replenished frequently during a long flight. Consequently, although fuel sequencing may be automated, deviations from the correct sequence due to automation failure may be difficult to determine simply by looking at the synoptic display. Moreover, the synoptic display of the fuel system may be 'congested' and the information difficult to assimilate unless the pilots' attention is drawn to the problem area by an automatic status or failure warning.

Finally, contemporary large rotorcraft are as complex as some large aeroplanes and they are operated by a minimum of two flight crew, yet there is a requirement, in EASA CS-29, for a low fuel level warning system.

Findings

From the above regulations it is clear that there is currently no requirement within EASA CS-25 or JAR-25 for a low fuel level warning on large aircraft. This is at variance to the smaller aircraft and to all rotorcraft which, under European regulations, require such a system as defined by the relevant EASA Certification Specifications CS-23, CS-27 and CS-29. Despite the lack of a regulation to install a low level fuel warning, most large aircraft certified to FAR-25, JAR-25 or EASA CS-25 do have an independent low fuel level warning system installed.

Safety Recommendations

If the low fuel level warning system is not independent, it can be inhibited by a failing fuel control system. An independent low level fuel warning system would enable the flight crew to be made aware of a failure of the automatic fuel control system and enable them to act accordingly, either by taking control of the fuel system or by landing prematurely. There are two main certification agencies for very large aircraft: the European Aviation Safety Agency which has taken over responsibility for certification of large aircraft from the Joint Aviation Authorities, and the US Federal Aviation Administration. Consequently, each of two safety recommendations is addressed to both bodies.

Safety Recommendation 2005-108

It is recommended that the European Aviation Safety Agency introduces into CS-25 the requirement for a low fuel warning system for each engine feed fuel tank. This low fuel warning system should be independent of the fuel control and quantity indication system(s).

Safety Recommendation 2005-109

It is recommended that the European Aviation Safety Agency should review all aircraft currently certified to

EASA CS-25 and JAR-25 to ensure that if an engine fuel feed low fuel warning system is installed, it is independent of the fuel control and quantity indication system(s).

Safety Recommendation 2005-110

It is recommended that the USA's Federal Aviation Administration should introduce into FAR-25 a requirement for a low fuel warning system for each engine feed fuel tank. This low fuel warning system should be independent to the fuel control and quantity indication system(s).

Safety Recommendation 2005-111

The Federal Aviation Administration should review all aircraft currently certified to FAR-25 to ensure that if an engine fuel feed low fuel warning system is installed, it is independent of the fuel control and quantity indication system(s).

Department for Transport

AAIB Bulletin S1/2005

SPECIAL

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Category: 1.1

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Persons on Board:	Crew - 18 Passengers - 293
Injuries:	Crew - None Passengers - None
Nature of Damage:	None
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	43 years
Commander's Flying Experience:	7,000 hours (of which 3,100 were on type) Last 90 days -120 hours Last 28 days - 85 hours
Information Source:	AAIB Field Investigation

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Notification

The event was reported to the AAIB by the operator and to the Dutch Transport Safety Board (DTSB) by the AAIB. Dutch investigators commenced the investigation with the assistance of the operator but the next day the DTSB formally asked the AAIB to assume responsibility for the investigation.

History of the flight

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The aircraft was cruising at Flight Level (FL) 380 in Dutch airspace when at 0330 hrs No 1 engine lost power. The flight crew secured the engine and the commander decided not to attempt to relight it but to continue towards Heathrow on three engines. The flight crew noticed that the fuel contents for the inner 1 fuel tank, which feeds engine No 1, was reading zero. Suspecting a possible fuel leak, a flight crew member was sent aft to inspect the engine area from the passenger cabin but nothing unusual was seen. However, soon afterwards, the crew observed the No 4 engine power fluctuate and noticed that the inner 4 fuel tank was also indicating zero fuel contents. The commander opened all the fuel crossfeed valves and the No 4 engine recovered. A 'MAYDAY' was declared and a diversion to Amsterdam Schipol Airport was initiated.

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Flight data recorders

An extract of the relevant recorded flight data is shown at Figure 1. Takeoff occurred at 1621 hrs with a total recorded fuel of 135,450 kg. As the aircraft climbed, normal fuel transfer occurred. At 1928 hrs, at FL 354, transfer from the centre fuel tank stopped; the tank quantity at that time was 5,300 kg. The aircraft continued en route until at 0328 hrs the inner 1 fuel tank quantity indication reached zero; 40 seconds later the No 1 engine started to run down and the engine was subsequently shutdown. At 0340 hrs the inner 4 fuel tank quantity reduced to zero and the No 4 engine started to run down. At 0345 hrs the flight crew attempted to restart the No 1 engine, but they were unsuccessful. Shortly afterwards at 0347 hrs, the flight crew manually started fuel transfer from the trim, centre and outer tanks to the four inner fuel tanks. At 0349 hrs there was an increase in all four inner fuel tank quantities. The inner fuel tank quantities continued to increase as fuel was transferred from the trim, centre and outer tanks. Touchdown was at 0410 hrs, with a total of 22,960 kg of fuel remaining, with the inner 1 through 4 fuel tank quantities of 2,641 kg, 5,922 kg, 5,370 kg and 2,583 kg respectively. Fuel continued to transfer to the inner tanks until the engines were shut down.

Aircraft examination

On arrival at Amsterdam, the Central Maintenance Computer produced a Post Flight Report (PFR) which detailed the cockpit effects and faults detected and recorded by the computer during the flight. The aircraft was then physically examined in accordance with advice provided by the aircraft manufacturer. This included verification of the fuel quantity indications against fuel contents measured using the tank magnetic level indicators. Tests were conducted on fuel pump operation, valve operation, cockpit lighting and warning displays; these tests did not reveal any abnormal operations. The engines were run and no problems were experienced including the starting of engine No 1. A manual refuel was carried out and the aircraft was flown on a non-revenue flight to Heathrow.

Following the aircraft's arrival at Heathrow, it was moved into a hangar for further investigation. The low-level fuel warnings for inner 1 and inner 4 fuel tanks were verified as working normally and valve operation was confirmed. After this, the two FCMCs, the two Fuel Data Concentrators (FDC), the two Flight Warning Computers (FWC) and the two System Data Acquisition Concentrators (SDAC) were inspected and removed from the aircraft for further testing. Inspection of the computers, their associated wiring, connectors and the security of their installations did not reveal any defects.

Computer tests

The computers removed from G-VATL were sent to their respective manufacturers for further tests. Prior to bench testing and full acceptance tests, data within the internal memories of the

two FCMCs, two FWCs and two SDACs were downloaded. The FDCs do not contain any internal memory but they were subjected to bench and full acceptance testing. These tests did not reveal any defects and all the computers performed as expected.

Downloaded computer data

The data downloaded from the FCMCs indicated that FCMC 2 suffered a loss of ARINC 429¹ data bus A at 1934 hrs and failures of some discrete output commands from the FCMC in control at that time. Which FCMC was in control is not known. The FWCs also reported two occurrences of ARINC 429 data bus A and data bus B output failures from FCMC 2. One instance of output failure can be accounted for by the flight crew's in-flight reset of FCMC 2. The other instance cannot be correlated against any crew action.

Safety action

On 10 February 2005 the aircraft operator issued a Company Notice to the effect that the inner tank fuel contents should be monitored and were any tank to show less than 1,500 kg, manual transfer should be initiated. Also, any ECAM fuel system warnings in flight would require the crew to monitor the fuel transfer for correct operation for the remainder of the flight.

On 15 February 2005 the aircraft manufacturer issued an Operator Information Telex / Flight Operation Telex (OIT/FOT) that contained operational advice to pilots which was to monitor the ECAM fuel page every 30 minutes. The OIT/FOT also provided a procedure to apply should automatic fuel transfer be lost.

FCMC Master/Slave determination

The basic A330/340 and the later model A340-500 and -600 aircraft have different fuel systems. On the A340-500 and -600 series each FCMC calculates the operation of the fuel system based on inputs from various data sources. To prevent confusion, only one FCMC can output commands; this is known as the 'master' FCMC. The master FCMC then commands valves and pumps to operate and it sends out warning and display signals to the FWCs. The other FCMC is known as the slave; it continues to calculate commands and monitors the master FCMC, but its ability to send out command signals is suppressed. The master FCMC is governed by health status; this status is determined internally by each FCMC. The healthiest FCMC is given master status. There is a possibility that the master FCMC may have an output failure and so may lose the ability to control the fuel system. However, the remaining slave FCMC may already be at a lower health status and cannot, therefore, become the master unit. This means that the master

¹ A Standard digital data highway for civil aircraft

FCMC may remain as master without the ability to provide command or warning signals. Therefore the following safety recommendation is made:

Safety Recommendation 2005-36

Airbus should review the FCMC master/slave determination logic of the affected Airbus A340 aircraft so that an FCMC with a detected discrete output failure or ARINC 429 data bus output failure cannot remain the master FCMC or become the master FCMC.

Low fuel level warning indications

In normal operation, the low fuel level warning for the inner fuel tanks is calculated by both FCMCs based on fuel quantity information from the FDCs. When the calculated fuel mass drops below 1,000 kg for more than 60 seconds, an ARINC 429 signal is sent from the master FCMC to the FWCs for the display of the relevant 'FUEL INR 1(2 3 4) LO LVL' warnings on the ECAM.

If both FCMCs have failed, then the FWCs use a discrete parameter generated by the FDCs to provide the warning of an inner tank low fuel level. The FDC low-level discrete parameter is set when the fuel level in the tank drops to a specific volumetric level, this means that it will trigger at various fuel masses due to changes in fuel density and temperature. For inner 1 and inner 4 fuel tanks the FDC can trigger the fuel low level discrete at a fuel mass of between 1,180 kg and 1,430 kg.

This means the low fuel level discrete from the FDC is usually received by the FWCs before the low level ARINC 429 signal from the master FCMC. The FWCs ignore the FDC discrete signal unless one or both FWCs has detected that both FCMCs have failed. This logic means that the back-up low level warning from the FDC is ignored if everything appears normal with the FCMCs. The expectation would be for the back-up system to have an overriding ability to trigger a warning and should not be dependant on the status of other systems. The following safety recommendation is made.

Safety Recommendation 2005-37

Airbus should review the logic of the low fuel level warnings on affected Airbus A340 aircraft so that the FDC low fuel level discrete parameter always triggers a low fuel level warning, regardless of the condition of the other fuel control systems.

Conduct of the investigation

Under the provision of the Civil Aviation (Investigation of Air Accidents and Incidents) Regulations 1996, the Chief Inspector of Air Accidents has ordered that an Inspector's Investigation be conducted into the circumstances of this serious incident. The investigation will work to establish the root cause for the initial failure of the automatic fuel transfer and the reason for the lack of fuel system warnings and proper indications during the flight.

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Figure 1 – An Extract of Relevant Flight Data

