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List of Appendices:

GLOSSARY OF ABBREVIATIONS USED IN THIS REPORT

°C	Degrees centigrade		JAA	Joint Aviation Authorities
AAIB	Air Accidents Investigation Branch		JAR	Joint Airworthiness Requirement
ADIRU	Air Data/Inertial Reference Unit		kg	kilogram(s)
AEEC	Airlines Electronic Engineering Committee		km	kilometre(s)
amsl	above mean sea level		kt	knot(s)
AOC	Air Operators Certficate		LCD	Liquid Crystal Display
APU	Auxiliary Power Unit		LP	Low Pressure
ARINC	Air Radio Incorporated		MAN	Manual
ATA	Air Transport Association		MCDU	Multipurpose Control and Display Unit
ATC	Air Traffic Control		MCT	maximum continuous thrust
BCD	binary coded decimal		MON	monitor processor
BITE	built in test equipment		MSN	manufacturers serial number
BNR	twos complement binary notation		N_1	Fan or LP compressor speed
CB	Circuit Breaker		ND	navigation display
CFO	Cruise First Officer		nm	Nautical Miles
CG	Centre of Gravity		OEB	Operations Engineering Bulletins
CMC	Central Maintenance Computer		PF	Pilot Flying
COM	command processor		PFD	primary flight display
CS	Certification Specification		PFR	Post Flight Report
CVR	Cockpit Voice Recorder		PNF	Pilot Not Flying
DIN	discrete input		QAR	Quick Access Recorder
DITS	Digital Information Transfer System		QNH	Corrected mean sea level pressure
DLRB	Data Loading Routing Box		QRH	Quick Reference Handbook
DMC	display management Computer		SACU	stand alone compensator unit
DOUT	discrete output		SCC	Senior Cabin Crew
DTSB	Dutch Transport Safety Board		SD	System Display
DU	Display Units		SDAC	System Data Acquisition Concentrators
EASA	European Aviation Safety Agency		SOP	Standard Operating Procedures
ECAM	Electronic Centralised Aircraft Monitor		STS	Status
EFIS	electronic flight instrument system		TFU	Technical Follow Up
EIS	electronic instrument system		TGT	Total Gas Temperature
EW/D	Engine and Warning Display		TR	Temporary Revision
FAA	Federal Aviation Administration		TSD	troubleshooting data
FAR	Federal Aviation Regulations		TSP	tank signal processors
FCDC	Flight Control Data Concentrator		UK	United Kingdom
FCMC	Fuel Control and Monitoring Computer		US	United States
FCOM	Flight Crew Operating Manual		UTC	Co-ordinated Universal Time
FDC	Fuel Data Concentrator		XFR	Transfer
FDR	Flight Data Recorder			
FL	Flight Level			
FMGEC	Flight Management Guidance and Envelope Computer			
FO	First Officer			
FPMU	fuel properties monitoring units			
FQI	Fuel Quantity Indication			
FWC	Flight Warning Computer			
FWD	Forward			
HP	High Pressure			
hrs	hours			
ICP	integrity check processor			
ILS	Instrument Landing System			

Air Accidents Investigation Branch

Aircraft Accident Report No: 4/2007 (EW/C2005/2/3)

Registered Owner and Operator:	Virgin Atlantic Airways Limited
Aircraft Type:	Airbus A340-642
Nationality:	British
Registration:	G-VATL
Location of Incident:	En-route from Hong Kong to London
Date and Time:	8 February 2005 at 0330 hrs
	All times in this report are UTC

Synopsis

The incident was reported to the AAIB by the operator who in turn notified the Dutch Transport Safety Board (DTSB). A Dutch investigation was opened but the following day a formal request was made by the DTSB for the AAIB to assume responsibility for the investigation. The AAIB investigation was conducted by:

Mr J J Barnett	Investigator-in-Charge
Miss G M Dean	Operations
Mr P Sleight	Engineering
Mr M Ford	Flight Recorders

Some 11 hours after takeoff, at about 0330 hrs with the aircraft in Dutch airspace and at Flight Level 380, the No 1 (number one) engine lost power and ran down. Initially the pilots suspected a leak had emptied the contents of the fuel tank feeding No 1 engine but a few minutes later, the No 4 engine started to lose power. At that point all the fuel crossfeed valves were manually opened and No 4 engine recovered to normal operation. The pilots then observed that the fuel tank feeding No 4 engine was also indicating empty and they realised that they had a fuel management problem. Fuel had not been transferring from the centre, trim and outer wing tanks to the inner wing tanks so the pilots attempted to transfer fuel manually. Although transfer was partially achieved, the expected indications of fuel transfer in progress were not displayed so the commander decided to divert to Amsterdam (Schipol) Airport where the aircraft landed safely on three engines.

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The investigation determined that the following causal factors led to the starvation of Inner fuel tanks 1 and 4 and the subsequent rundown of engine numbers 1 and 4:

1. Automatic transfer of fuel within the aircraft stopped functioning due to a failure of the discrete outputs of the master Fuel Control and Monitoring Computer (FCMC).

2. Due to FCMC ARINC data bus failures, the flight warning system did not provide the flight crew with any timely warnings associated with the automated fuel control system malfunctions.

3. The alternate low fuel level warning was not presented to the flight crew because the Flight Warning Computer (FWC) disregarded the Fuel Data Concentrator (FDC) data because its logic determined that at least one FCMC was still functioning.

4. The health status of the slave FCMC may have been at a lower level than that of the master FCMC, thus preventing the master FCMC from relinquishing control of the fuel system to the slave FCMC when its own discrete and ARINC outputs failed.

During the investigation the AAIB issued six safety recommendations. Two were published in Special Bulletin S1/2005 on 08 March 2005 and four more in an interim report published in the February 2006 AAIB Bulletin.

1   Factual Information

1.1   History of the flight

1.1.1   Pre-departure

The flight was scheduled to depart Hong Kong on 7 February 2005 at 1535 hrs (2335 hrs local) with a scheduled arrival time at London Heathrow of 0450 hrs the next day. There were three pilots operating the flight, a captain who was the aircraft commander, and two first officers, one designated as the operating first officer (co-pilot) and one as cruise first officer (CFO). The commander was the Pilot Flying (PF) for the flight.

The weather forecast for Heathrow indicated there was a probability of low visibility operations at the time of arrival so the commander decided to load additional holding and diversion fuel, nominating Prestwick, Scotland, as the alternate airport.

There was one relevant entry in the technical log prior to departure. The two Fuel Control Monitoring Computers (FCMCs) had been reset at separate times on the previous flight sector from Sydney to Hong Kong.

During the pre-flight preparation period for the flight to London, there was one FCMC2 and one FCMC1 failure. The flight crew successfully reset both computers by following the Quick Reference handbook (QRH) procedure on each occasion.

1.1.2   Incident flight

Whilst taxiing for departure from Hong Kong the flight crew noticed a brief flicker on the Electronic Centralised Aircraft Monitor (ECAM) indicating 'FCMC FAULT' but were not sure which FCMC was shown. No action was taken.

The aircraft took off at 1621 hrs. Shortly after takeoff there was an 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 cruise level. When the aircraft was at its initial cruising level the flight crew attempted a FCMC2 reset using the computer reset procedure in the QRH. The reset was unsuccessful. The flight continued and there were no further fuel system warnings, cautions or messages throughout the remainder of the flight.

During the course of the flight the pilots took it in turns to take rest in a bunk. Whilst the commander was resting, command of the aircraft and the PF duties reverted to the operating co-pilot whilst the CFO occupied the left hand seat.

The operating pilots carried out periodic reviews of the ECAM systems pages during the flight. On each handover to a replacement crew member, following a rest period, a briefing was conducted which included information about the position of the aircraft, the ATC controlling authority and the technical status of the aircraft.

At around 0200 hrs the commander returned from his rest period and took over the PF duties again. At about 0330 hrs, with the aircraft in Dutch airspace and level in the cruise at Flight Level (FL) 380, the No 1 (number one) engine lost power. The flight crew carried out the ECAM 'ENG 1 FAIL' actions which included a prompt to consider relighting an undamaged engine. The commander decided not to attempt a relight of the engine but to continue to Heathrow on three engines, so the flight continued with the No 1 engine shutdown.

After reviewing the aircraft systems and status pages, the flight crew noticed that the fuel contents for the Inner 1 tank, which feeds No 1 engine was reading zero. They were puzzled by the indication and concerned about a possible fuel leak. The commander asked the co-pilot to go aft, call the CFO from his rest, and ask him to go and inspect the left wing and engines.

The commander then called the Senior Cabin Crew (SCC) member to the flight deck and briefed him on the state of the aircraft and the cabin service requirements. While he was doing so the operating co-pilot drew the commander's attention to the No 4 engine pointing out that its power was reducing. The commander immediately opened all the fuel cross feed valves and, he thought, he also opened the outer tank transfer valve, whereupon the No 4 engine recovered. The flight crew then observed that the Inner 4 tank contents indication was zero. At this stage the commander recognised that they had a fuel management problem.

The CFO returned to the flight deck and reported that he was unable to see anything abnormal on the No 1 engine. The commander then discussed the various options for the onward flight with both First Officers (FOs) and decided that if they were able to relight No 1 engine, they would continue to Heathrow but if not, he would declare a MAYDAY and divert the flight.

An attempt was then made to relight the No 1 engine using the QRH procedure

but this was unsuccessful. While the relight attempt was in progress, the commander reviewed the fuel system and noted that fuel was not coming out of the centre tank and that there was only 2,700 kg in each wing. He asked the co-pilot to transfer fuel manually from the trim and centre tanks into the wing tanks. At that time there were significant quantities of fuel located in the trim and centre fuel tanks; the total fuel on board was in excess of 25,000 kg.

At 0348 hrs the commander transmitted a MAYDAY which included information that the aircraft had a fuel management problem and one engine was shut down. He requested a diversion to Amsterdam.

The co-pilot carried out the instruction to transfer fuel using the 'TRIM TANK FUEL UNUSEABLE' procedure from the QRH (see Appendix A) On completion of the procedure the flight crew could not see any evidence that the fuel was transferring and, believing that it was not doing so, looked for another procedure.

Searching through the FCOM the co-pilot found the 'FUEL T TK XFR FAULT' procedure (see Appendix B). This procedure was then carried out by the CFO together with the commander while the co-pilot operated as PF. The pilots then became aware that although the contents of the centre tank were increasing and fuel appeared to be transferring into it, fuel did not seem to be transferring out of it. They then looked for a procedure to address this problem. They found and carried out the 'FUEL CTR/INR XFR FAULT' procedure from the FCOM (see Appendix C). In this procedure there is a note that if fuel is less than 35 tonnes, the centre tank fuel is unusable. At that time the flight crew believed that both the centre, trim and outer wing tank fuel contents were unusable and calculated that they had 10 tonnes of useable fuel on board.

Fuel transfer was in fact taking place but because the crew did not see all the indications that they expected on the system display, doubt and confusion concerning the exact fuel status remained in their minds for the rest of the flight.

The diversion to Amsterdam continued and the commander resumed the PF role. The flight was assigned a dedicated frequency for the approach by ATC and at 0410 hrs the aircraft landed without any further technical problems.

1.2   **Injuries to persons**

	Crew	Passengers	Others
Fatal			–
Serious	–	–	–
Minor	–	–	–
None	18	293	–

1.3   **Damage to aircraft**

No damage sustained.

1.4   **Other damage**

No other damage sustained.

1.5   **Personnel information**

1.5.1   Commander: Male, aged 43 years

Licences:	Airline Transport Pilot's Licence
Aircraft ratings:	A340, A320
Licence Proficiency Check:	Valid to 31 May 2005
Operator Proficiency Check:	Valid to 31 May 2005
Line check:	Valid to 30 August 2005
Medical certificate:	Class 1 renewed 15 October 2004

Flying experience:		
	Total all types:	7,000 hours
	Total on type:	3,100 hours
	Total last 90 days:	120 hours
	Total last 28 days:	85 hours
	Total last 24 hours:	12 hours
Previous rest period:	60 hours	

1.5.2   First Officer (Operating):   Male, aged 37 years

Licence:	Airline Transport Pilot's Licence
Aircraft ratings:	A340
Licensing Proficiency Check:	Valid to 31 June 2005
Operator Proficiency Check:	Valid to 31 June 2005
Line check:	Valid to September 2005
Medical certificate:	Class 1 renewed 19 July 2004

		Flying experience:	Total all types:	7,690 hours
			Total on type:	4,130 hours
			Total last 90 days	200 hours
			Total last 30 days:	70 hours
			Total last 24 hours:	12 hours
		Previous rest period:	60 hours	

1.5.3   First Officer (Cruise)   Male, aged 31 years

	Licence:	Airline Transport Pilot's Licence	
	Aircraft ratings:	A340, B737, HS125	
	Licensing Proficiency Check:	Valid to 28 July 2005	
	Operator Proficiency Check:	Valid to 28 July 2005	
	Line check:	Valid to 7 October 2005	
	Medical certificate:	Class 1 renewed 24 January 2005	
	Flying experience:	Total all types:	4,445 hours
		Total on type:	380 hours
		Total last 90 days	128 hours
		Total last 30 days:	58 hours
		Total last 24 hours:	12 hours
	Previous rest period:	60 hours	

1.5.4   Flight duty schedule

The flight crew had been scheduled for a series of duties over a nine-day period including rest days; this was the final sector of the schedule. The flights were between the United Kingdom and Australia and involved large time zone changes. The operator had an approved flight time limitations scheme. The scheduled flight duty period was 14 hours 15 minutes; the allowable flight duty period, which may vary in accordance with the amount of in-flight rest taken, was in excess of this. There were no variations or extensions of duty period applicable to this flight.

1.6   Aircraft Information

1.6.1   General information

Manufacturer	Airbus
Type	A340-642
Aircraft Serial Number	376
Year of manufacture	2001
Powerplant	4 Rolls-Royce Trent 556-61 turbofan engines
Total airframe hours	6,498.32 hours
Total airframe cycles	906
Certificate of Registration	UK Registered on 31 October 2003
Certificate of Airworthiness	Transport Category (Passenger) issued by the UK Civil Aviation Authority valid until 30 October 2006
Certificate of Maintenance Review	Issued 17 August 2004 and valid until 16 February 2005
Departure fuel quantity	136,200 kg
Landing fuel quantity	22,960 kg
Maximum takeoff mass	368,000 kg
Actual takeoff mass	367,211 kg
Takeoff centre of gravity	23.3% Mean Aerodynamic Chord
Maximum landing mass	259,000 kg
Actual landing mass	254,671 kg

1.6.2   Aircraft general description

The Airbus A340-600 is the latest and largest variant in a family of four-engined long haul aircraft. The first variants in the A340 aircraft family were the A340-200 and A340-300. Later enhancements of the type saw the introduction of the A340-500 and A340-600. Airbus developed the A340-500 for long-range operations, giving it a range of 8500 nm, and the A340-600 for a larger seating capacity, albeit with a lower range of 7900 nm. The technology used in the A340-500/600 was derived from the A340-200/300; these variants retained the same basic cockpit layout and display philosophy of the entire Airbus fleet. However, there were some differences in the system design from the older models including a significant change in the fuel system design.

1.6.3   EFIS/ECAM

The Airbus A340-600, in common with other modern Airbus aircraft, is equipped with an electronic instrument system (EIS). This consists of six liquid crystal cockpit displays, two displays in front of each pilot and two central displays.

The pilot displays are part of the electronic flight instrument system (EFIS) and provide primary flight instrumentation information on the primary flight display (PFD) and the navigation display (ND).

The two central displays, mounted vertically, form the Electronic Centralised Aircraft Monitoring (ECAM) system. The upper display is the Engine and Warning Display (EW/D), and the lower display is the System Display (SD).

Figure 1

Upper and Lower ECAM Displays

1.6.3.1   Engine and Warning Display

The EW/D provides essential information about the status of the aircraft systems. The upper part of the display provides primary engine instrument information, total fuel quantity on board and its disposition, fuel used, and the status of the flaps and slats. The lower section of the display has two areas of information. The left area provides warning and caution information as well as crew procedures. The right area provides secondary failure information relating to the system affected by a warning or information relating to inhibited systems or temporary actions such as activating the anti-ice system.

If there are any status messages stored for display on the SD then the EW/D displays the symbol 'STS' at the bottom of its screen.

System failure messages on the EW/D are colour-coded and prioritised with alerts classified in three levels according to the importance and urgency of the corrective action required.

1.6.3.2   System Display

The System Display (SD) has the capability to display 13 different system pages, the cruise page or the status page. The display has two areas: the upper section of the screen provides information based on the selection of the display, the lower section contains permanent data that is always present regardless of the page selection. This permanent data contains information on the total and static outside air temperatures, the time, the aircraft's gross weight and its centre of gravity.

In flight, the 'default' cruise page is generally displayed. This page shows additional engine parameters, such as fuel burn, oil quantity and vibration levels as well as cabin air and pressurisation parameters.

The flight crew can display a system status page by manual selection or after the completion of an ECAM procedure as it provides a summary of the aircraft condition. The display has three areas. The left panel lists all the limitations, approach procedures, cancelled cautions and information. The right panel has two headings; INOP SYS lists all the systems which are currently inoperative, MAINTENANCE lists all the systems with class 2 failures.

The flight crew can select any one of the 13 systems pages manually or, if the system detects a warning, caution or exceedance, it will automatically display the relevant status page for that particular system. The system will also display other pages automatically depending on the phase of flight.

The system pages are:

System Page	Parameters Shown
ENG	Additional information to that on the EW/D, relating to the engine
BLEED	Information relating to the engine bleed air system
PRESS	Information relating to the aircraft cabin pressurisation
EL/AC	Information relating to the AC electrical systems
EL/DC	Information relating to the DC electrical systems
HYD	Information relating to the hydraulic systems
APU	Information relating to the APU and its associated systems
COND	Information on the air conditioning system
DOOR	Information on the aircraft access doors
WHEEL	Information relating to the landing gear and wheels
F/CTL	Information relating to the primary and secondary flying controls
FUEL	Information relating to the fuel system (This will be described in more detail later)
C/B	Status of the circuit breaker panels

1.6.4   Display management system

Three display management computers (DMC) provide the display functions for the six display units (DU) on the A340 instrument panel. These receive data from the various aircraft systems via ARINC 429 buses. The DMCs decode the data to provide the display units with the information needed to display the representative symbols on their LCD displays.

In flight the three DMCs each provide information to two display units, so that:

DMC 1 provides information to the captain's primary flight display and navigation display.

DMC2 provides information to the first officer's primary flight display and navigation display.

DMC 3 provides information to the EW/D and SD displays.

To achieve a high level of redundancy, each aircraft system provides the same ARINC 429 data to each of the three identical DMCs; these can provide information to any display unit. Consequently, if one DMC is faulty, the flight crew are able to select another DMC to provide information to the display unit screens.

1.6.5   System data acquisition concentrators

Two identical system data acquisition concentrators (SDAC) acquire data and generate signals. Some of these signals go to the three DMCs which use them to generate displays of system pages and engine parameters. Other signals go to the flight warning computers which use them to generate ECAM messages and alerts.

System Data Acquisition Concentrators (SDAC) 1 and 2 also provide data on the fuel system status to the DMCs including information on the status of the cross feed valves, engine LP valves and engine fuel pumps.

1.6.6   Flight warning computers

Two identical flight warning computers (FWC) generate alert messages, memos, aural alerts and synthetic voice messages. The detailed functioning of these computers is described in paragraph 1.6.11.

1.6.7   Fuel control and management computers

Two fuel control and management computers (FCMC) automatically control the fuel system but provision is made for manual override. Each FCMC determines its own health level through continuous monitoring of its status. The FCMC with the healthiest level takes on the role of 'master' FCMC.

Each FCMC receives inputs from numerous aircraft systems and uses these to manage the functions of the fuel system such as fuel transfers, refuelling, jettison, centre of gravity management and fuel quantity. Each FCMC has two ARINC 429 output buses; BUS A and BUS B.

The FCMCs provide the fuel system status and fuel quantity data to the DMC with inputs from their ARINC 429 output buses A and B.

> DMC 1 is supplied data from FCMC1 BUS B and FCMC2 from BUS A.

DMC2 is supplied data from FCMC1 BUS A and FCMC2 from BUS B.

DMC 3 is supplied data from FCMC1 BUS B and FCMC2 from BUS A.

In relation to the fuel data received by a DMC, during normal operation a DMC will select the ARINC 429 input data from the master FCMC. However, if a DMC receives no ARINC 429 data from FCMC2, it will switch to using the ARINC 429 data from FCMC1, even if this is not the master FCMC.

A detailed description of the fuel system including the functioning of the FCMCs begins at paragraph 1.6.9.3.

1.6.8   Fuel system SD page

The fuel system SD page provides the flight crew with synoptic information on the status of the fuel system on the aircraft. The display consists of details of pump and valve operation, individual tank fuel quantities and transfer arrows, displayed during manual or automatic fuel transfer. An example SD fuel page is shown at Figure 2.

In normal operation the source of the status display data is from the master FCMC to the DMC. In the event of failure of the master and slave FCMC, the DMC uses limited information from the SDAC to display the status of the centre tank fuel pumps, main and standby engine fuel pumps, trim tank fuel pumps, engine LP fuel valves, cross feed valves, cross feed pipe and the jettison system. The DMC selects the SDAC data when both FCMC have failed or when the master FCMC no longer provides a valid output, with the slave FCMC still outputting data. For fuel quantity information, the DMC can use data from both the master and slave FCMC.

With a failure of both FCMCs, the DMC is not able to provide a status display of the fuel quantity, fuel temperature or the fuel transfer arrows. However, if the master FCMC has no output and the slave FCMC is still providing data, then the display can still show fuel quantity and temperature, but not fuel transfer arrows.

Appendix D shows a list of the items displayed on the fuel status display with the data source.
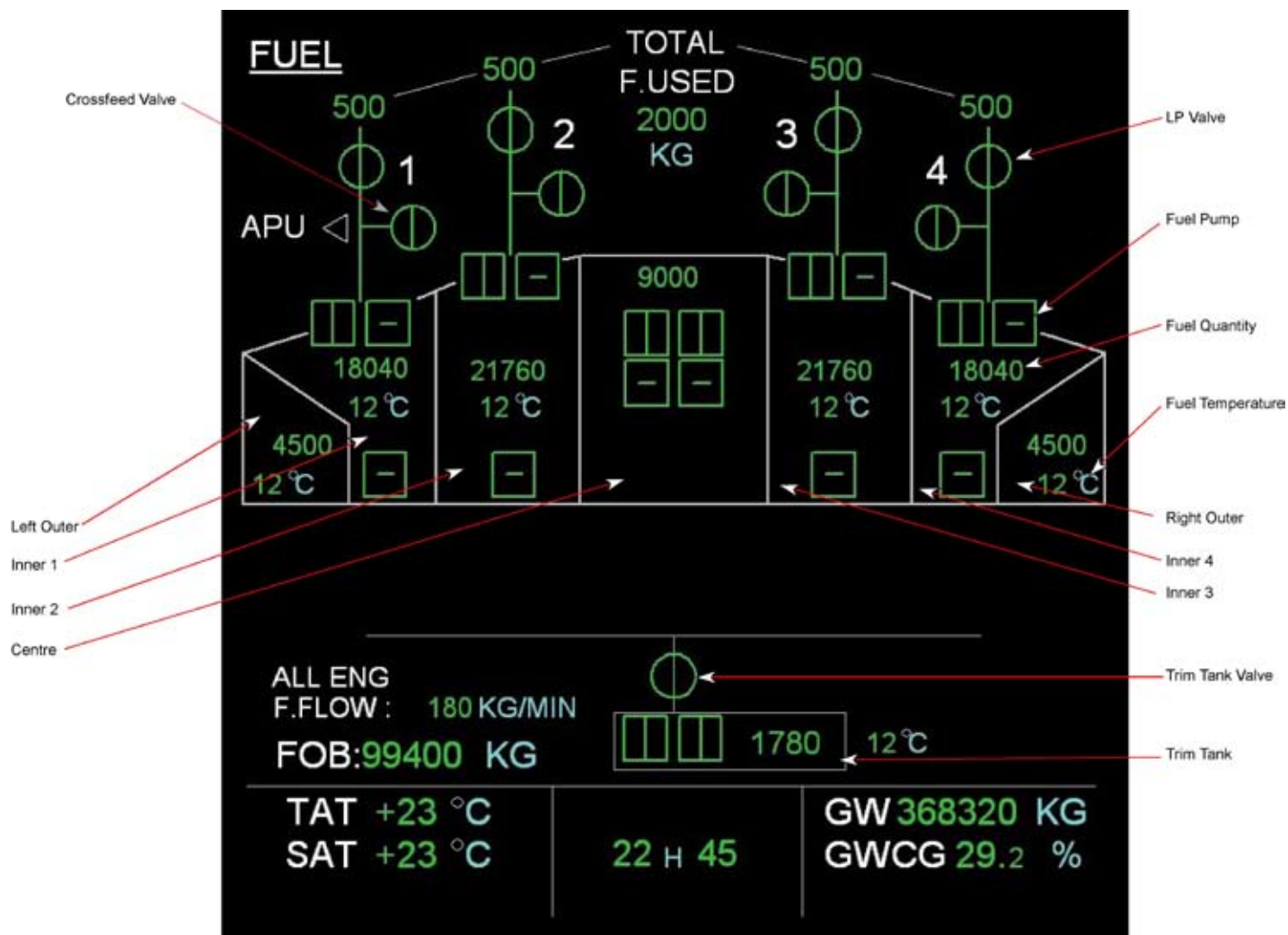
Figure 2

Fuel status display

1.6.9 Fuel system general

1.6.9.1 Fuel tanks layout

The fuel on the A340-600 is stored within eight separate fuel tanks as shown in Figure 3. These tanks are identified as:

- Left and right outer fuel tanks.
- Four inner fuel tanks numbered 1 through 4.
- Centre fuel tank.
- Trim fuel tank in the horizontal stabiliser.

A collector cell within each inner fuel tank provides fuel for the main and standby engine-feed fuel pumps. During normal operation, and with fuel in the inner tank, jet pumps keep the respective collector cell full of fuel.

Vent surge tanks, installed outboard of each outer tank and to the right of the trim tank, provide tank venting.
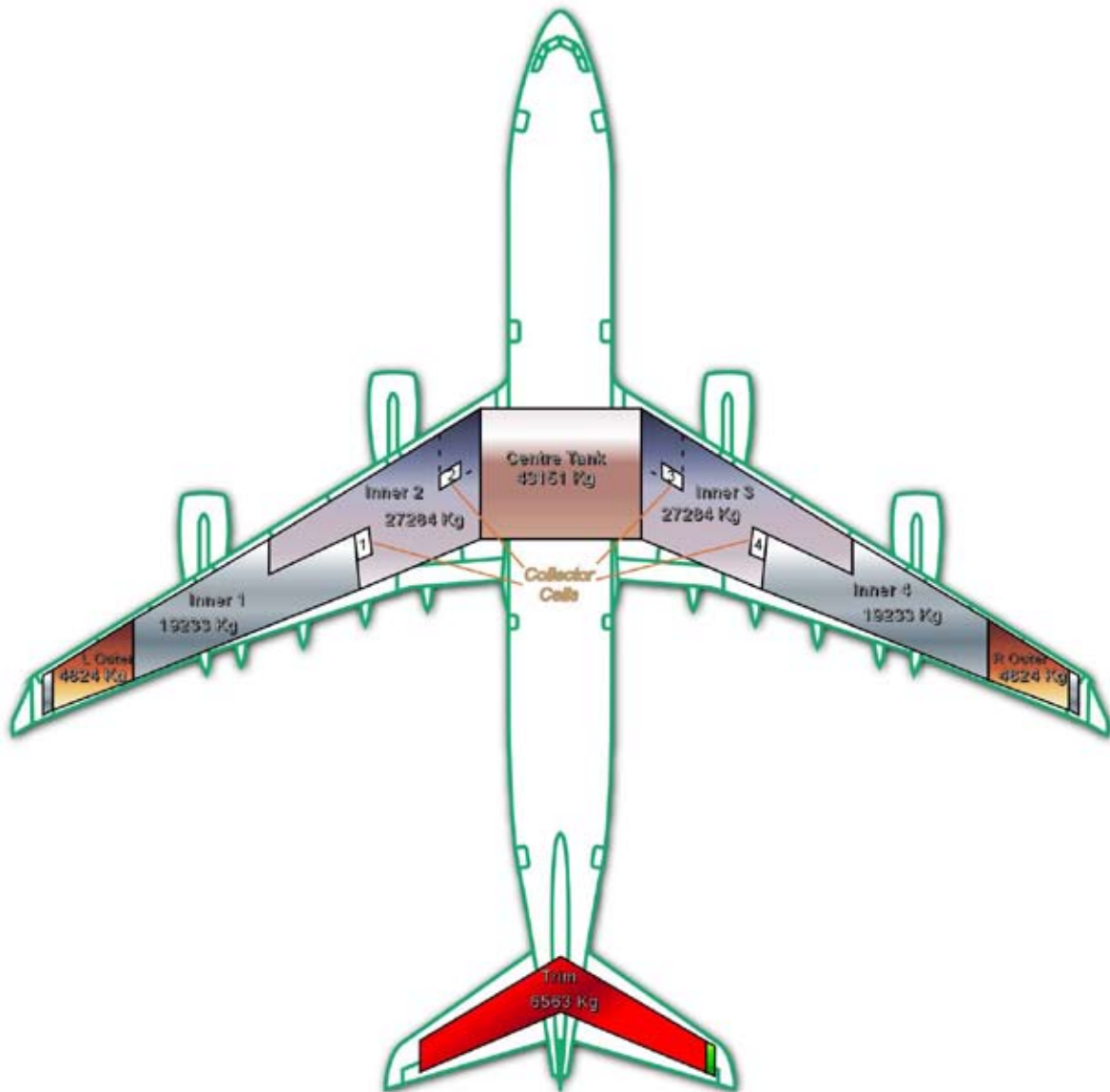
Figure 3

A340-600 Fuel Tanks Layout

The capacity of each fuel tank is:

L OUTER	INNER 1	INNER 2	CENTRE	INNER 3	INNER 4	R OUTER
4,824 kg	19,233 kg	27,284 kg	43,151 kg	27,284 kg	19,233 kg	4,824 kg
10,635 lb	42,402 lb	60,151 lb	95,131 lb	60,151 lb	42,402 lb	10,635 lb
			TRIM			
			6,563 kg			
			14,470 lb			

Capacity figures relate to a specific gravity of 0.785

1.6.9.2   Pump and valve layout

Appendix E Figure 1 shows the schematic layout and references of the pumps and valves within the fuel system.

1.6.9.3   Fuel control system

1.6.9.3.1   General

The fuel system is designed to be fully automatic in normal operation. The two FCMCs control the fuel system although the flight crew can override the automation by making manual selections on the fuel control panel, a sub-panel on the flight deck overhead panel.

1.6.9.3.2   FCMC

1.6.9.3.2.1   Architecture

The computer architecture is shown in simplified form in Figure 4 below:

An FCMC consists of several separate circuit boards, each with a specific function. These functions are: a command/monitor board, an integrity check board, discrete[1] input boards and discrete output boards. The architecture within the unit consist of a command processor (COM), a monitor processor (MON), an integrity check processor (ICP), discrete input (DIN), discrete output (DOUT) and the ARINC interface. DIN takes the discrete inputs from the various pumps, valves and switches in the fuel system and processes the analogue data into digital signals for later processing in the COM and MON.

_____

1   A signal which conveys one of two states such as on or off, open or closed etc.
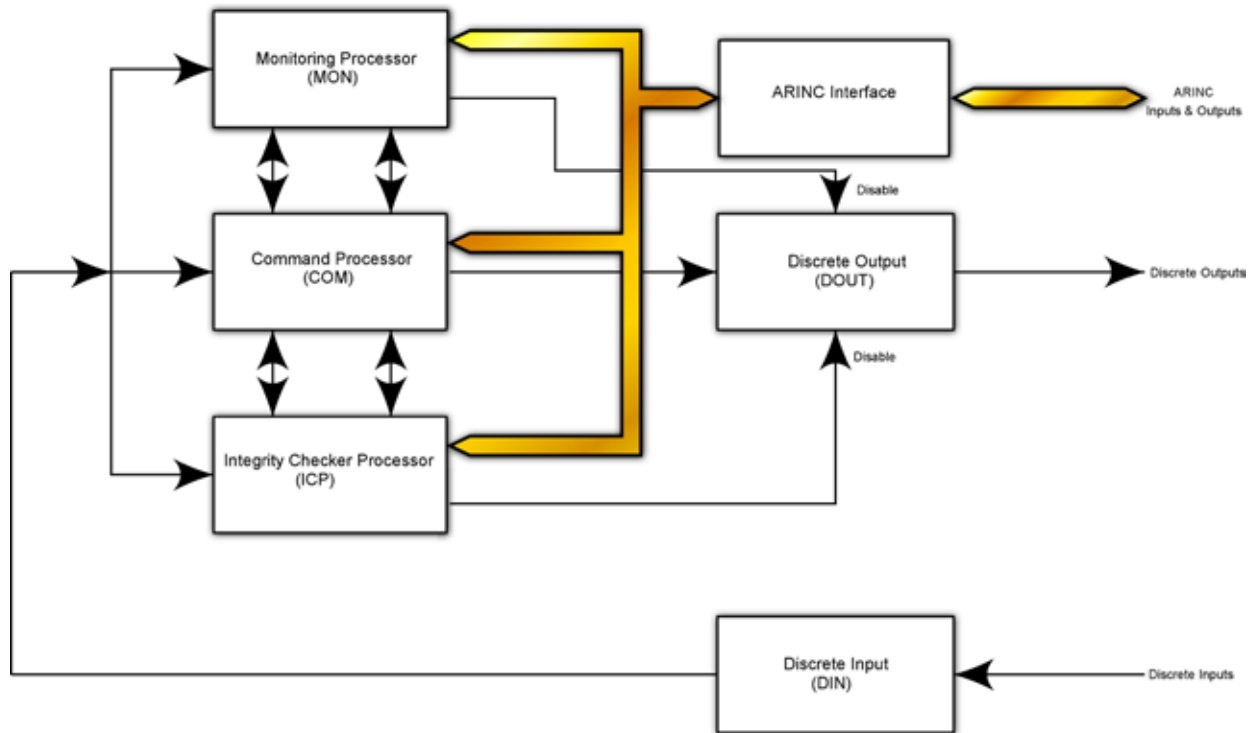
Figure 4

FCMC Simplified Block diagram

DOUT takes instructions from the COM and converts the digital signals into analogue commands for control of the pumps, valves and overhead panel indications. The DOUT is only able to output commands when the FCMC is master. The ICP and MON also have the ability to isolate the DOUT in the event of detected failures.

The ARINC interface receives processes and transmits the internal commands from the COM on the FCMC ARINC output buses. It also receives the ARINC input data on the ARINC input buses and processes data for use by the ICP, COM and MON functions.

The COM carries out the control function of the system and uses the inputs from DIN and the ARINC interface to make decisions on valve control, pump control, warning indications, fuel quantity and display indications. The COM communicates these decisions via the DOUT or the ARINC interface to the various external systems. The MON carries out the same computations and compares the outputs from the COM with those decisions made by the MON; a discrepancy between the two processors generates a COM/MON comparison failure and an FCMC fault.

In addition to the MON, which is evaluating the fuel management, the ICP checks the integrity of the fuel quantity calculations. The COM carries out the computation of fuel quantity based on the inputs from the FDC and uses this to produce the output seen on the FUEL SD page. The ICP also receives the same information from the FDC and carries out its own computations using dissimilar algorithms; its processes include the generation of low fuel level warnings. If there is a discrepancy between the COM and the ICP computations then the ICP should normally disable the COM discrete and ARINC outputs; resulting in an 'FCMC1(2) FAULT' annunciation on the ECAM and the handover of master control status to the other FCMC.

1.6.9.3.2.2 FCMC software

For the fuel control systems to function correctly the processors within the FCMC require software. This is loaded either at manufacture or can be installed in-situ via a floppy disc. The software, once loaded onto the FCMC, modifies the FCMC standard number. In addition each Flight Load version number defines the level of software that has been loaded. The FCMCs from G-VATL were at standard level 2.13, with a software Flight Load of version 7.

As discussed later, in the event of a detected discrepancy, an oversight at software level Flight Load 7 removed the ability of the ICP to cut off the COM outputs.

1.6.9.3.2.3 Health levels

Each FCMC determines its own health level through continuous self-monitoring of its status. The FCMC with the healthiest level takes on the role of master. Initially this occurs immediately after the power-up tests.

There are eight health levels with the healthiest being level 0 and the worst being level 7.

Health level	Conditions
0	FCMC has no reported failures following power-up tests.
1	Loss of ARINC data from the ADIRUs, FMGECs[1] or FCDCs.
2	Any one of – Single discrete input or output failure. A loss of ARINC from TSP. A non volatile memory chip failure. A ARINC bus A ,B or C external wrap failure, detected by COM or MON. An internal ARINC bus wrap test failure.
3	Either – More than one discrete input or output failure or Both ARINC Bus A and B external wrap[2] failure, detected by COM or MON.
4	Any one of – A failure of the discrete output interface. A failure of the discrete input interface. A failure of the Serial Communications Interface. Both ARINC Bus A and B external wrap failures detected by the COM and MON. A ARINC bus C external wrap failure detected by the COM and MON. A failure of the ARINC interface of an essential component.
5	Any one of – One or more TSP ARINC inputs has failed, FQI accuracy status is then failed. FCMC ARINC interface failure with a failed FQI accuracy status. ICP integrity check failure. COM –MON comparison failure.
6	Any one of – Aircraft configuration pin programming failure. ICP aircraft configuration comparison failure. ICP pin programming failure. Software compatibility test failure.
7	Any one of – COM hardware failure MON hardware failure ICP hardware failure.

1   Flight Management, Guidance and Envelope Computers.
2   A self-monitoring function of the ARINC outputs.

The two FCMCs communicate their health levels through an ARINC bus and a set of analogue discrete lines. If there is a discrepancy between the health level communicated on the ARINC bus and the health level indicated by the discrete lines, then the detecting FCMC will store a 'FCMC ALT HEALTH MISMATCH' fault message in its memory.

The FCMCs can be 'reset' in flight, by the flight crew, through the use of the FCMC1(2) RESET CB (circuit breaker) on the overhead panel. This provides a signal to the computer to carry out an interrupt of power to its processors. The length of time the CB is 'out', before resetting, determines the sort of reset that is accomplished. A 'cold' reset occurs if the CB remains 'out' for longer than 500ms; this clears all the latched faults and resets the health level to 0. A reset of the CB before 500ms, causes a 'warm' reset, which does not clear the latched faults and the health levels remain at the pre-reset level.

1.6.9.3.2.4 Input/Output

To command fuel pumps and valves, the FCMCs send out discrete signals on analogue output lines, normally in the form of a path to earth. The discrete output board (DOUT) in the FCMC processes the output discretes. This board receives the required output data from the command processor, which is also monitored by the MON, and converts the output data for transmission.

During normal operation only the master FCMC sends discrete outputs from its DOUT board. The slave FCMC's discrete outputs from its DOUT process are disabled by its COM. If, however, the COM is malfunctioning, then the MON and ICP will isolate the DOUT board.

Pages 2 and 3 of Appendix E show a list of components (as illustrated on Page 1 of the Appendix) that are directly commanded by the master FCMC discrete outputs.

The FCMC also receives feedback from the pumps and valves it commands via discrete inputs. For the fuel pumps, the FCMC receives discrete inputs showing if the pump is energised and if there is low pressure in the supply line. Similarly, each valve provides discrete inputs to the FCMC indicating whether it is open or closed. Additionally, the FCMC receives discrete inputs from the overhead fuel panel switches and other systems which affect the fuel system operation, such as landing gear selection and nose gear compression. The three discrete input boards (DIN), inside each FCMC, receive the discrete inputs and then interpret the data before sending it to the relevant internal COM, MON or ICP processor.

The COM and MON processes, using a closed loop, monitor the discrete commands sent out by the COM. Therefore if a valve is commanded open, then the COM expects the valve to indicate that it is open via its discrete input. If the COM does not receive a valve open discrete, it assumes the valve has failed, fails that particular component within the system, and logs this in the troubleshooting data; it also sends any associated warnings, such as fuel transfer failures, on the ARINC lines to the FWC. However, the detection of an individual valve or pump not responding to a command will not render the FCMC inoperative and the DOUT remains functional because the MON sees the COM is correctly commanding the system.

Each FCMC receives data inputs on ARINC 429 data buses, which carry information from the following aircraft system computers:

> Flight Control Data Concentrator (FCDC) Numbers 1 and 2
> Central Maintenance Computer (CMC) Numbers 1
> Data Loading Routing Box (DLRB) for software uploading
> Fuel Data Concentrator (FDC) Numbers 1 and 2
> Air Data/Inertial Reference Unit (ADIRU) Numbers 1 and 2
> Flight Management Guidance and Envelope Computer (FMGEC)
>   Numbers 1 and 2

The FCMC also has seven ARINC 429 output buses which are:

> BUS A – DATA OUTPUT
> BUS B – DATA OUTPUT
> BUS C – FQI (Fuel Quantity Indication) - REFUEL PANEL ONLY
> BUS D – COM TEST
> BUS E – MON TEST
> BUS G – ICP TEST
> BUS J – INTER FCMC COMMUNICATION

Figure 5 shows the ARINC output communication paths for BUS A and BUS B, as well as the ARINC input paths from the FDC.

The FCMC uses an external wrap-around of the ARINC output bus to monitor the status of the output signals. The COM and MON both monitor this wrap-around of the ARINC data. If they detect a failure, the failure is stored in the troubleshooting memory and the health level of the FCMC is degraded (see above). For example if ARINC BUS A was detected as having a faulty signal on the external wrap-around to the computer, then the FCMC would store a

'CP ARINC RX17 MISSING LABEL' fault in its memory, indicating a failure of the ARINC BUS A external wrap-around. This would also degrade the health of the FCMC and produce a 'FCMC1(2) FAULT' on the ECAM.
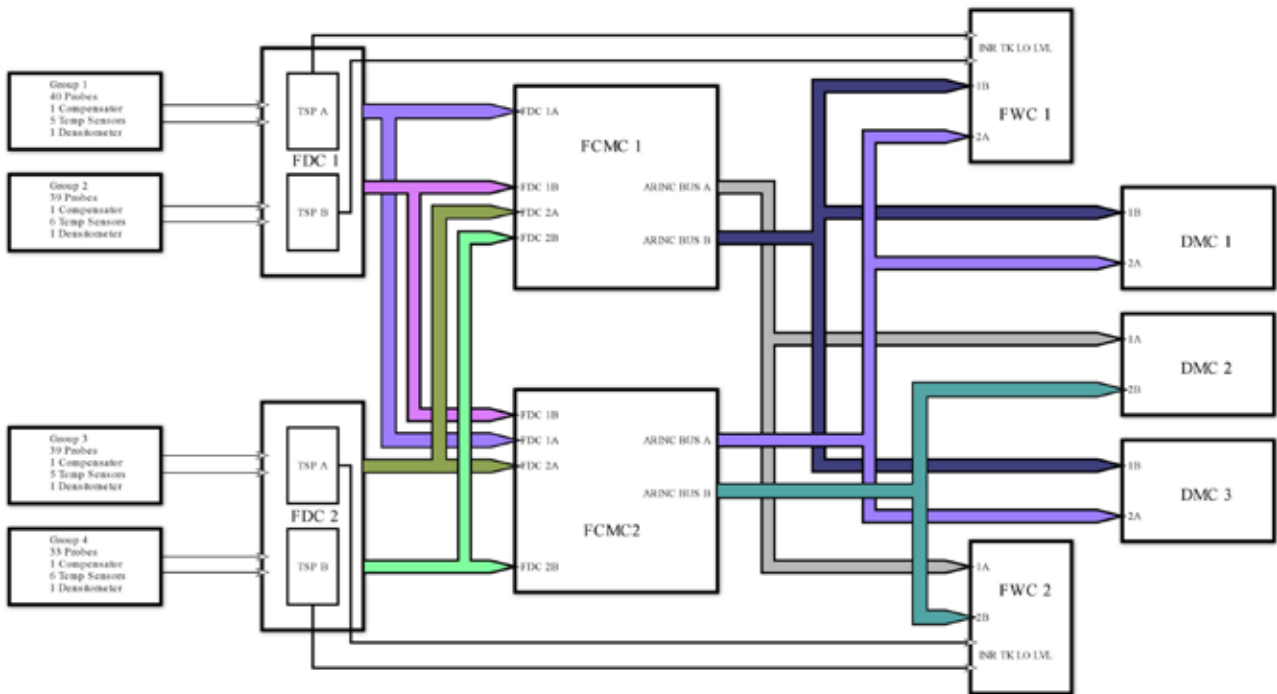
Figure 5

FCMC ARINC data bus connections

1.6.9.3.2.5 Manual control and overhead panel

The overhead fuel control panel is illustrated in Figure 6:

This panel provides the flight crew with the ability to manually control the fuel system. In normal operation each of the switches would be deselected (set to the OUT position) so that the FCMCs have automatic control over the fuel system with no lights illuminated on the panel.

In the event of a pump failure, the associated pump switch would indicate 'FAULT' in amber and a message would appear on the ECAM requiring the illuminated switch to be set to the OFF position. Placing a pump switch to OFF illuminates the white 'OFF' symbol in the switch.

The panel also allows for the selection of the cross feed valves to OPEN indicated by the amber 'OPEN' symbol on the switch.
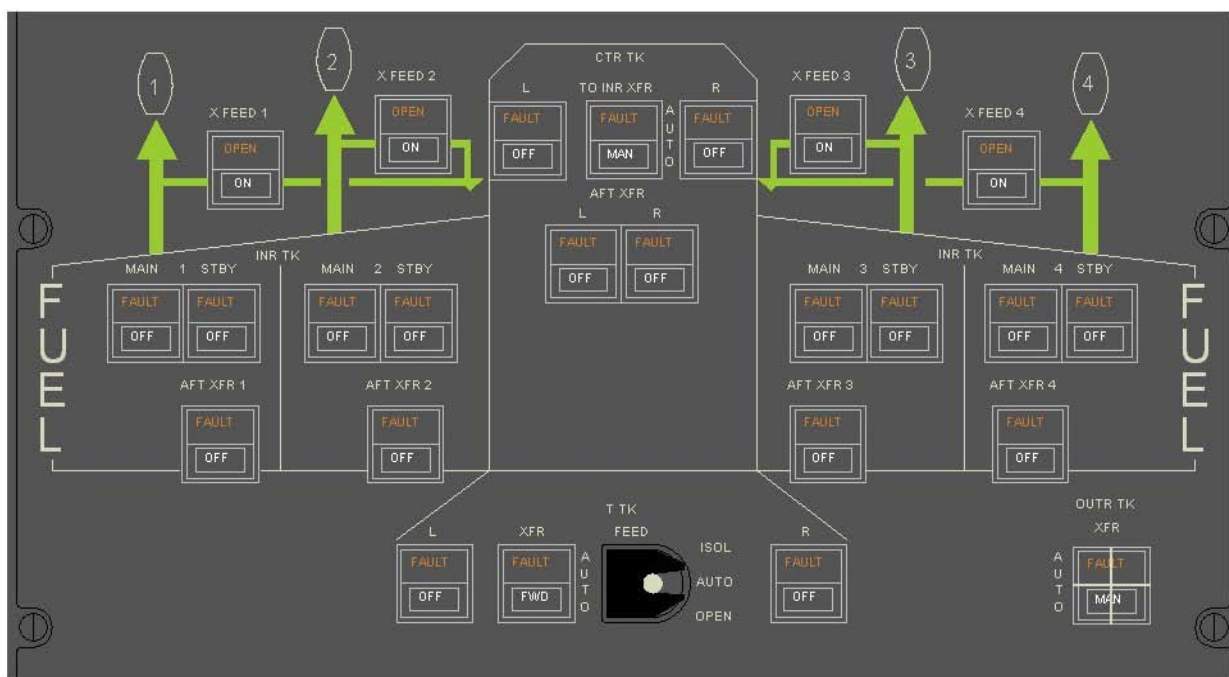
Figure 6

Overhead Fuel Control Panel

If the automatic system fails then the panel contains switches to enable manual fuel transfer. There are three manual transfer switches, CTR TK TO INR XFR, OUTR TK TXFR and T TK XFR. Operation of these switches to MAN (or FWD for the trim tank) will override the FCMC and open the transfer valves allowing the fuel transfer.

Following a fuel transfer fault, the master FCMC commands the associated manual transfer switch to produce its amber 'FAULT' caption.

1.6.9.4   Fuel quantity

The fuel quantity SD page is illustrated in Figure 7 below.

Each fuel tank has fuel probes, densitometers and fuel temperature sensors for use in fuel quantity calculations. The probes provide a capacitance proportional to the fuel level. Each FDC receives information from approximately half of the fuel tank measuring components. Within each FDC are two independent tank signal processors (TSP) which receive the analogue information from the fuel tank probes, densitometers and temperature sensors and process the data to provide independent ARINC 429 outputs to the FCMC.
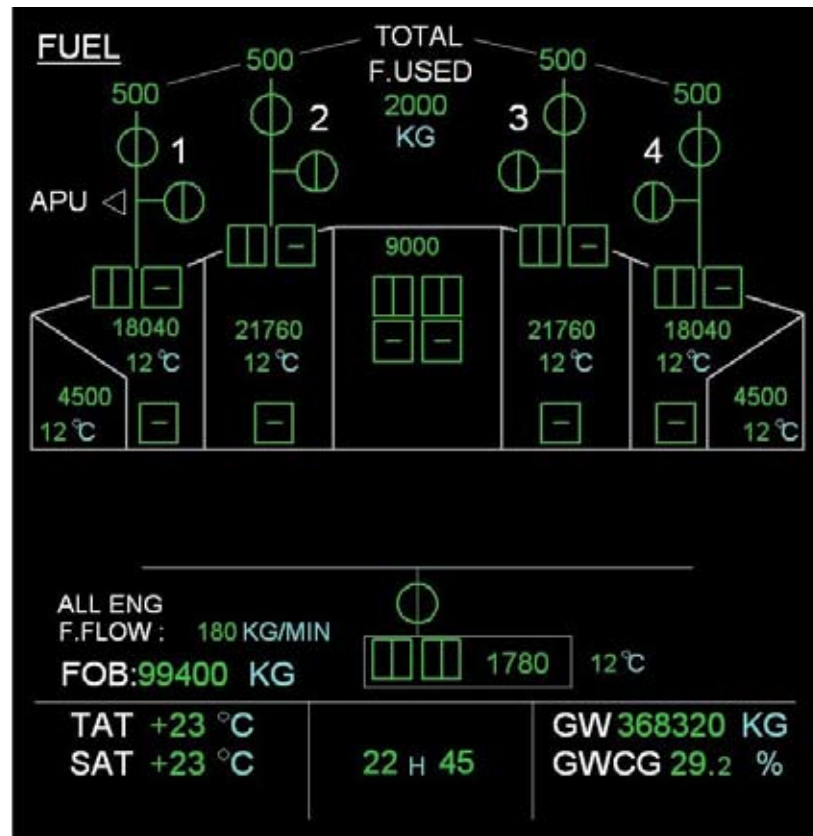
Figure 7

Normal 'in cruise' fuel status display

The FCMC COM and the ICP independently calculate the fuel quantity. A discrepancy between the COM and ICP calculated fuel quantities causes a failure of the FQI and an FCMC1(2) FAULT indication on the ECAM. However, either FCMC is able to provide fuel quantity data to the DMC, regardless of whether it is master or slave. The logic within the DMC will select the master FCMC as the source for the fuel quantity information. However, if neither FCMC is designated as Master, the DMCs select FCMC1 by default.

When the capacitance of the fuel probes reaches a pre-determined level, the FDCs also provide an independent fuel tank low-level analogue discrete output from each of the four TSPs.

1.6.9.5   Fuel temperature

The fuel status page on the SD display indicates fuel temperature for all the fuel tanks except the centre tank. Temperature sensors located in each fuel tank provide the data for the indication. There are nine dual temperature sensors and four single temperature sensors. The dual sensors are located in the lowest

regions of the fuel tanks and consist of two separate temperature bulbs enclosed in a single housing. As the fuel temperature changes, the resistance of the sensors also changes in proportion, this is detected by the FDC before being processed and passed on to the FCMCs for the display of fuel temperature and calculation of fuel quantity. One of the dual sensors provides data to FDC1 and the other to FDC2. The sensors for the inner fuel tanks are located in their respective collector cells.

The single fuel temperature sensors are located in the fuel properties monitoring units (FPMU) and the stand-alone compensator unit (SACU), both of which provide data on the properties of the fuel in the fuel tanks for fuel quantity calculations. The temperature detection method in the single temperature sensor is the same as for the dual temperature sensors; however only one of the two FDCs detects the resistance change.

When an FCMC detects a failure of a temperature sensor it records it in the troubleshooting data. The failure of a single sensor in a dual sensor fuel tank temperature probe, subsequently detected by the FCMC COM processor, produces a class 3 fault; with no indications to the flight crew or required action in flight. However, a dual sensor failure results in a class 1 fault being recorded, although this does not result in the display of an ECAM fault warning. The only flight deck effect is an amber 'XX' on the fuel SD display against the relevant fuel tank temperature indication.

The FCMC ICP can also detect faults with the temperature sensors. Should the ICP detect a fault rather than the FCMC COM, this will cause a class 1 fault, and an ECAM display of an 'FCMC1(2) FAULT' message.

However, at FCMC Flight Load 7 there was a problem with the failure detection software which resulted in the spurious reporting of an 'FCMC FAULT' related to the fuel tank temperature-sensors. Normally, a fuel tank temperature-sensor fault does not degrade the health of the FCMCs because the fault is external to the computer. At Flight Load 7 the spurious fault reporting could reduce the FCMC health to level 5 and generate 'FCMC FAULT' messages. A fuel tank temperature-sensor fault does not produce a 'FDC FAULT' message.

1.6.9.6   Fuel transfer – automatic control

1.6.9.6.1   Centre to Inner tanks

The master FCMC controls the automatic fuel transfer, from the centre tanks to the inner tanks, by commands to the respective pumps and valves in the

system. To transfer fuel from the centre tank, the two centre tank transfer pumps supply fuel into the main fuel transfer gallery. The opening of the inner tank fuel transfer valves then allows centre tank fuel to enter the inner tanks.

When the Inner 1 (or 4) fuel tanks contents drop below 17,200 kg, the master FCMC commands the inner 1 (or 4) fuel tank transfer valve to open and allow the fuel to transfer. Once the fuel tank contents reaches 18,200 kg the inner 1 (or 4) fuel tank transfer valve is commanded closed, stopping the transfer.

In a similar way for Inner 2 (or 3) fuel tanks, if the tank contents drop below 24,700 kg the Inner 2 or 3 fuel tank transfer valve is opened, and then closed when the contents rise above 25,700 kg.

This cyclic filling of the inner fuel tanks continues until the centre tank is empty. Once the centre tank is empty the centre tank transfer pumps are switched off by the FCMC.
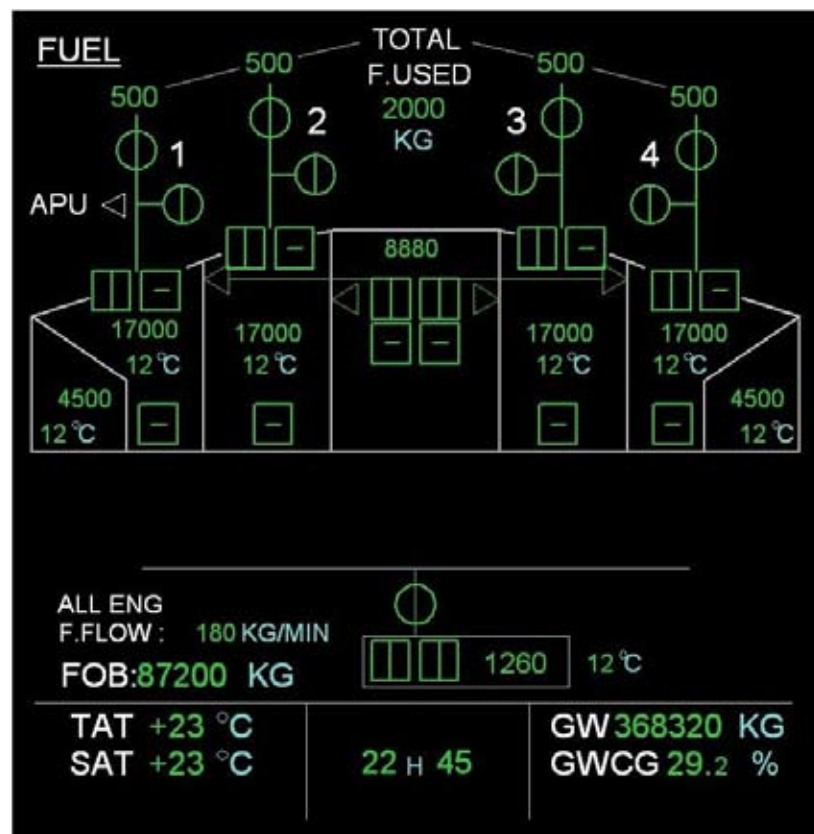
Figure 8

Fuel status display during a centre to inner tank fuel transfer

1.6.9.6.2   Outer to Inner 2 and 3

Automatic fuel transfer between the outer tanks to Inner tanks 2 and 3 is by gravity. When the fuel quantities of Inner tanks 2 or 3 drop below 2,000 kg, the master FCMC commands open the two inter tank transfer valves allowing fuel to transfer. When the tank quantities reach 2,500 kg the inter tank transfer valves are closed and fuel transfer stops.

This cyclic transfer continues until the outer tank is empty.
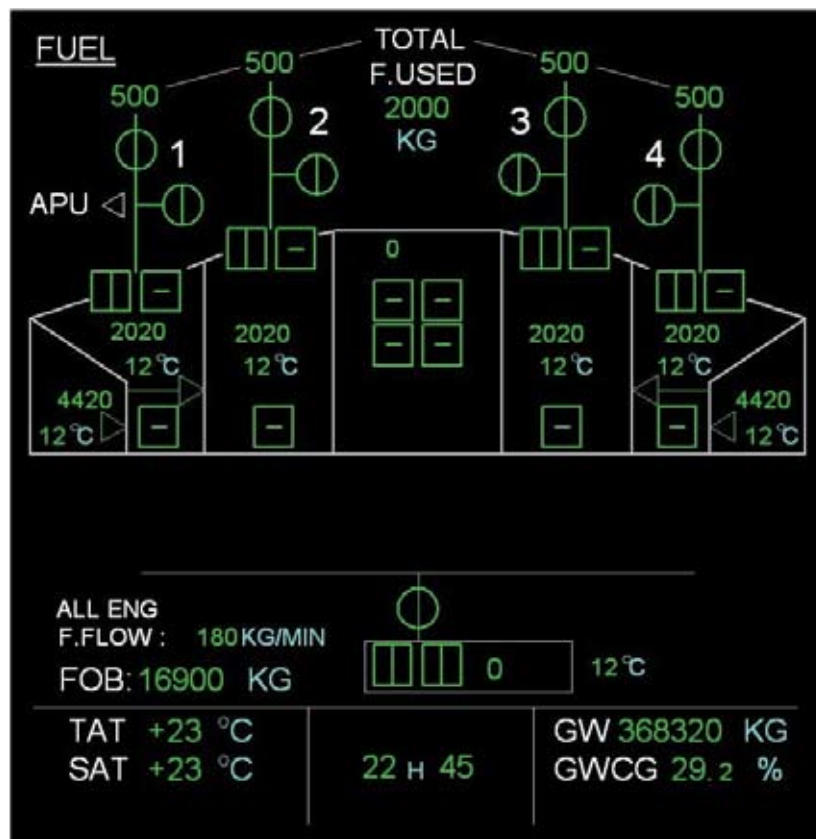
Figure 9

Fuel status display during the outer to inner tank fuel transfer

1.6.9.6.3   Outer to Inner 1 and 4

Automatic fuel transfer between the outer tanks to the inner fuel tanks 1 and 4 is also by gravity. When the fuel quantities of inner fuel tanks 1, or 4, drop below 2,000 kg, the master FCMC commands the inner fuel tank 1, or 4, inlet valve, and the outer tank inlet valves, to open. After the inner 1 and 4 tank quantities reach 2,500 kg the valves are closed and fuel transfer stops.

This cyclic transfer continues until the outer tank is empty.

1.6.9.6.4   Trim tank transfer

To control the aircraft's centre of gravity (CG), fuel is transferred automatically to and from the trim fuel tank inside the horizontal stabiliser. The master FCMC calculates the CG and compares it to a target value; if there is a need to transfer fuel to maintain the CG position, the master FCMC commands fuel transfer either aft or forward.

The master FCMC can command forward and aft trim fuel transfer for CG purposes only under certain conditions. One condition is that the aircraft's flight level must be above FL255 (about 25,500 feet). Consequently, there is usually an aft fuel transfer as the aircraft passes FL255 during its climb to initial cruising altitude, with several adjustments throughout the remainder of the flight.
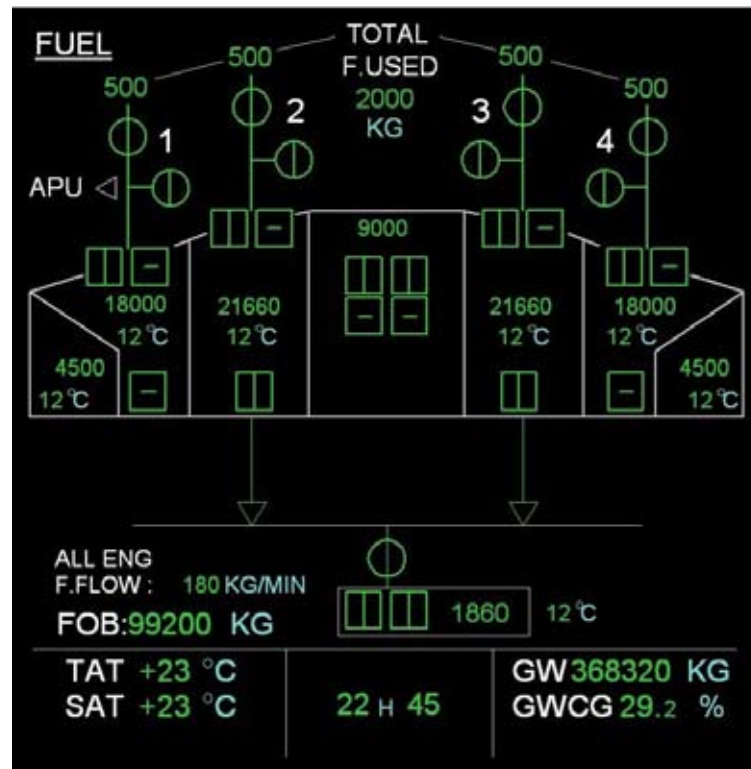
Figure 10

Auto aft trim transfer

If the fuel contents of any one of the four inner fuel tanks drops below 4,000 kg, the master FCMC commands the system to transfer fuel forward from the trim tank to the inner fuel tanks, via the auxiliary refuel valve and the four inner tank transfer valves.

Forward transfer of trim tank fuel should also take place when the aircraft is 45 minutes from its destination or when the aircraft descends below FL245.

1.6.9.7   Fuel transfer – manual control
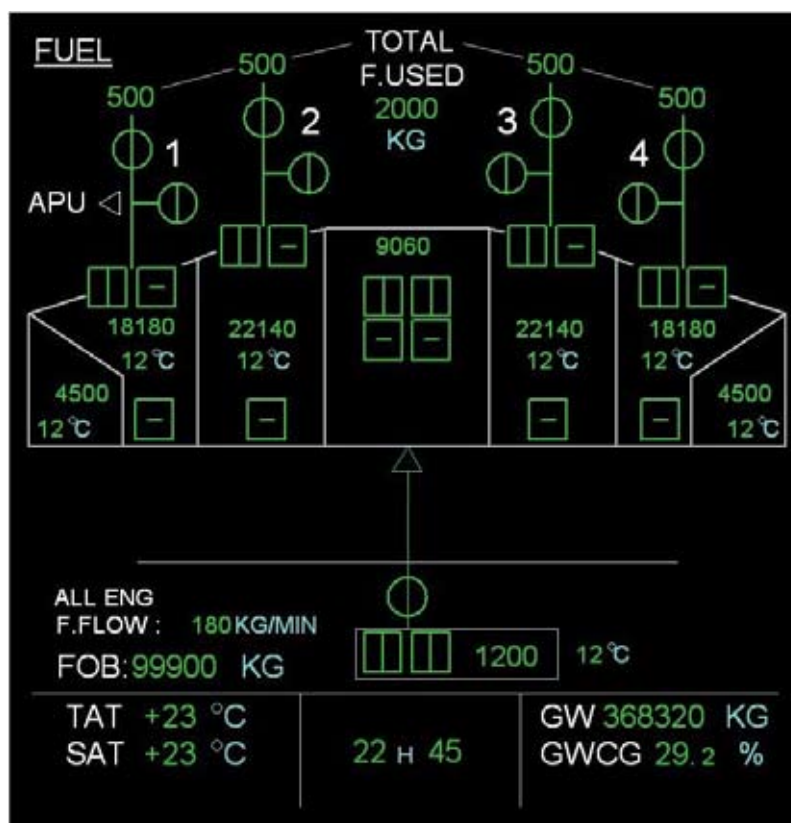
Figure 11

Fuel status display during auto forward trim transfer

The flight crew can override the FCMC and manually command the transfer of fuel through the use of selection switches on the overhead FUEL panel. Pushing the CTR TK TO INR XFR switch causes the MAN light to illuminate in the switch and commands the centre tank transfer pumps to transfer fuel to all of the inner tanks. Manual fuel transfer is indicated on the SD display by solid transfer arrows whereas hollow arrows indicate automatic transfer.

If the OUTR TK XFR switch is depressed, the MAN light illuminates in the switch and fuel transfers by gravity to the inner tanks.

Operation of the T TK XFR switch causes the FWD light to illuminate in the switch. The trim tank isolation valve and the auxiliary forward transfer valve are commanded open and fuel transfers from the trim tank forward to the centre tank.

During manual transfer operations, the flight crew have to monitor the fuel tank quantities to prevent overfilling of the fuel tanks.
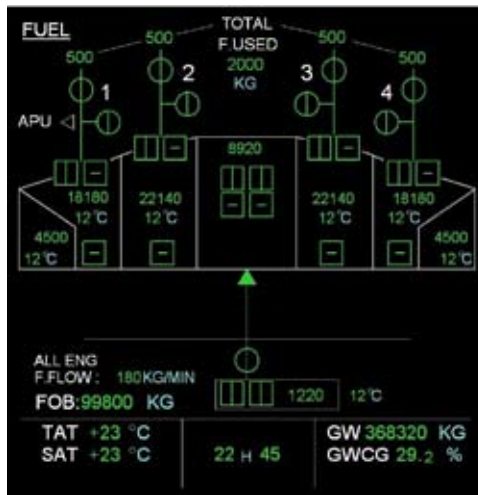
Figure 12a

Fuel status display during manual
trim tank transfer
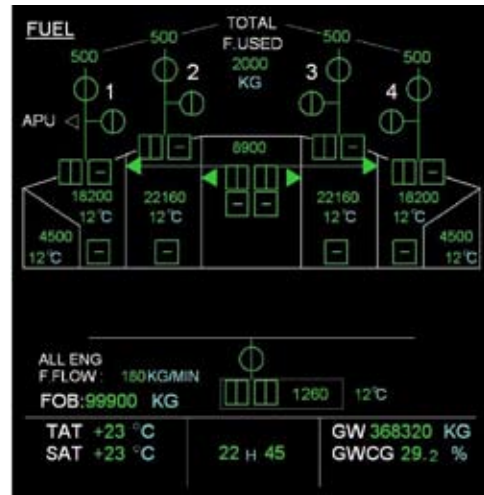
Figure 12b

Fuel status display during manual
centre to inner fuel transfer
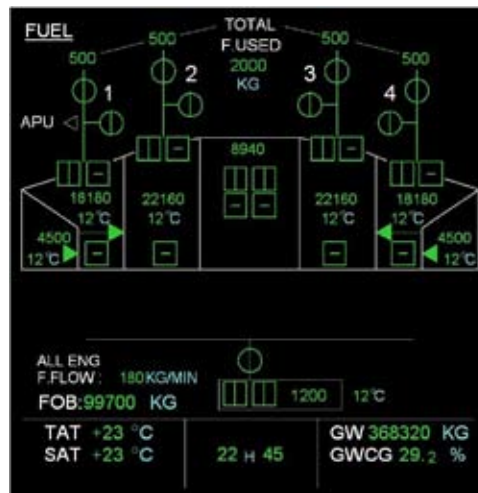
Figure 12c

Fuel status display during manual
outer to inner fuel transfer

1.6.10   Engine fuel supply

The main and standby engine feed pumps, located in the collector cells of each
inner tank, supply fuel to each engine. Each inner fuel tank provides fuel to
its respective engine, so inner fuel tank 1 supplies engine 1, inner fuel tank 2
supplies engine 2, inner fuel tank 3 supplies engine 3 and inner fuel tank 4
supplies engine 4.

The low pressure (LP) fuel shut-off valves control the fuel fed to the engine.
There is one LP valve for each engine and it is located in the engine fuel feed

line. The valves are not controlled by the FCMC system but are operated directly from manual switch selections on the flight deck. The LP valve is opened when the engine master switch is placed to ON. Placing the engine master switch to OFF will close the valve. The valve will also close if the related engine fire push-switch is operated. The FCMCs and the SDACs receive position data from the LP valves, which then send the valve status information for display on the FUEL SD Display.

In normal operation there are separate fuel paths to each engine from their respective inner tanks but manually operated cross feed valves can provide a means of supplying more than one engine from a single inner fuel tank. However, when a cross feed valve is manually selected open, fuel enters into the fuel gallery. Manually opening a second cross feed valve allows fuel to feed more than one engine from a single inner tank, via the fuel gallery. The FCMCs and the SDACs receive position information from the cross feed valves and then send this position information to the DMC for display on the Fuel SD page.
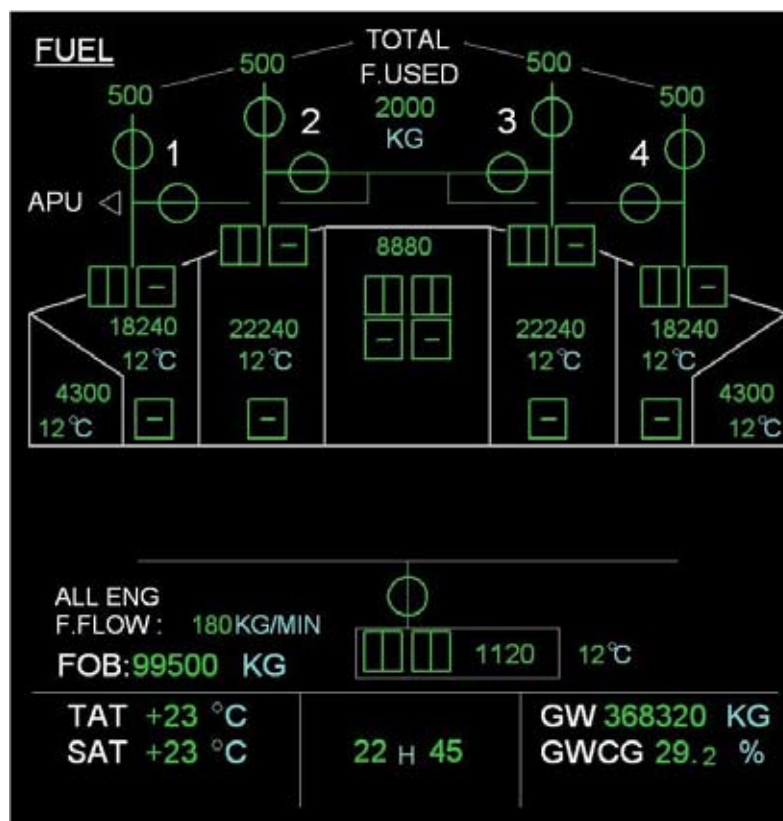
Figure 13

Fuel status page whilst all cross feed valves are open

1.6.11   Flight warning system

The A340-600 has two flight warning computers (FWCs) which provide: control signals for the display of warning messages on the EW/D, aural warnings, master caution and warning light illumination, and automatic display of system pages on the SD. They also provide information for the display of the inoperative systems on the status display.

An FWC has four warning/caution levels. These levels determine the type of warning displayed and the associated attention getters as shown below:

Level	Type	EW/D	Light	Aural Warning
0	Memo	Green Message Display	None	None
1	Simple Caution or Advisory	Amber message display	None	None
2	Master Caution	Amber message display and procedure	Master Caution	Single Chime
3	Master Warning	Red message display and procedure	Master Warning	Repeating Chime

In normal operation only one FWC provides data to the DMCs. However, if either FWC detects a level 2 or level 3 warning, then the FWC that received the warning takes immediate control and annunciates the warning, via the DMC, to the flight crew.

For the fuel system warnings, FWC1 is connected to ARINC 429 bus FCMC1B and FCMC2A and FWC2 is connected to ARINC 429 bus FCMC1A and FCMC2B. Additionally the FWCs receive discrete inputs from FDC1 and FDC2.

1.6.12   Fuel warnings

1.6.12.1   Low fuel level

In normal operation the master FCMC will calculate the fuel quantity, in kilograms, in the inner tanks. The normal trigger level for a low fuel warning is 1,000 kg, from calculations within the FCMC. The COM processor determines when the inner tank fuel quantity has dropped below 1,000 kg for more than 60 seconds. The ICP also determines, using different algorithms, whether the inner tank fuel quantity has dropped below 1,000 kg for more than 60 seconds. The inner tank fuel low level signals from the COM and ICP are sent via an 'OR' logic gate so that either processor can trigger the master FCMC inner tank low level ARINC output.

In addition, the FCMC ICP carries out a check function of the fuel low-level output. If the ICP detects a mismatch between an expected FCMC low-level warning output and the actual FCMC output, then the ICP should cut off all the outputs from the affected FCMC, handing master control over to the other FCMC.

However, with software standard Flight Load 7, incorrect programming removed the ability for the ICP to shut off the FCMC outputs when it detected an anomalous inner tank low fuel quantity.

The master FCMC sends the inner tank fuel low-level signal on both its ARINC 429 buses to the FWCs. The FWCs take this signal and display the following:

- 'FUEL INR 1(2,3,4) LO LVL' on the EW/D

- An associated procedure on the EW/D to open the cross feed valves and to initiate manual fuel transfer

- Automatic display of the fuel system page on the SD

- A single chime aural warning

- Master caution lights illuminated

In addition the master FCMC, via discrete outputs, commands the following on the overhead panel:

- 'CTR TK TO INR XFR' switch 'FAULT' light illuminated

- 'OUTR TK XFR' switch 'FAULT' light illuminated

- 'T TK XFR' switch 'FAULT' light illuminated

If the FWC detects that both FCMC1 and FCMC2 are faulty it will then utilise the inner tank fuel low level discrete from the Fuel Data Concentrators (FDCs). The 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 704 kg and 840 kg. The resulting warning display is the same as for an inner tank fuel low level warning detected by the master FCMC.

In addition, the master FCMC commands the related fuel quantity figure for the fuel tank with the low level, to turn from green to amber.

1.6.12.2   Collector cell not full

The master FCMC calculates the fuel load in the collector cells of each inner fuel tank. The master FCMC sends a warning to the FWCs, via ARINC 429, if the calculated cell fuel quantity drops below 750 litres for more than 60 seconds, and it has not triggered an inner tank fuel low-level warning. On receiving this signal the FWCs display the 'CELL 1(2 3 4) NOT FULL' warning on the EW/D, accompanied by a single chime aural warning and the illumination of the master caution light. The EW/D displays the associated procedure and the SD displays the fuel system page. In addition, the collector cell fuel quantities also appear in small boxes next to the fuel pump status displays for each tank, on the fuel SD.

The 'CELL 1(2 3 4) NOT FULL' warning can occur due to cell depletion as a result of the pumps in the cell supplying two engines or more via the cross feed.
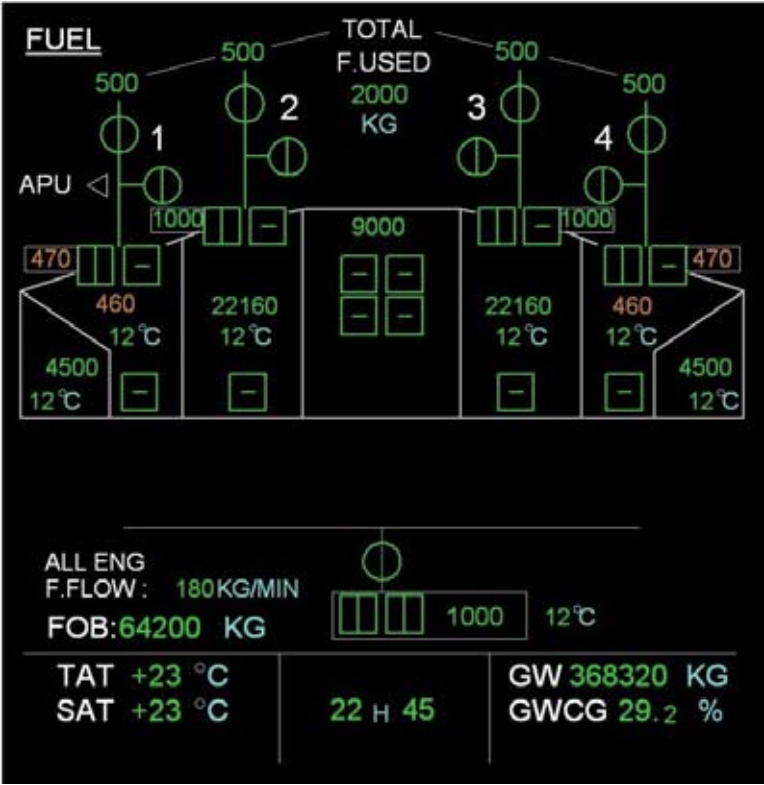
Figure 14

Fuel status page with low fuel quantity and collector cell not full in tanks
Inner 1 and 4

1.6.12.3   Pump Low Pressure

In the event of low fuel pressure output from the main or standby engine fuel supply pump, a pressure switch in the affected pump is activated and illuminates the amber 'FAULT' light in the affected pump switch on the overhead panel.

The low pressure switch also sends a discrete signal to the FCMCs and the SDACs. If a main engine fuel pump low pressure discrete is received by the master FCMC, it sends an ARINC signal to the FWC to produce the 'FUEL MAIN 1(2,3,4) FAULT' level 1 message on the EW/D and switches the SD display to the fuel system page. The fuel system page will show the affected engine fuel pump symbol in amber, but there is no aural warning or master warning light. Should the associated standby engine fuel pump also indicate a low fuel pressure to the master FCMC, it sends an ARINC 429 signal to the FWC to produce the 'FUEL MAIN 1(2,3,4) + STBY 1(2,3,4) FAULT' level 2 warning. The warning appears on the EW/D along with an aural warning and a master caution light; the fuel system page will also automatically display on the SD and the symbols for the affected pumps will be coloured amber.

The DMC controls the display of the fuel pump status on the fuel SD page. In normal operation the master FCMC provides the fuel pump status for the fuel page display. However if the DMC detects a failure of the output of the master FCMC, the DMC logic switches its data source for the fuel pump status to the SDACs.

If the FWC detect that both FCMCs have failed, then their internal logic switches the data sources for the engine fuel pump status to the SDACs.
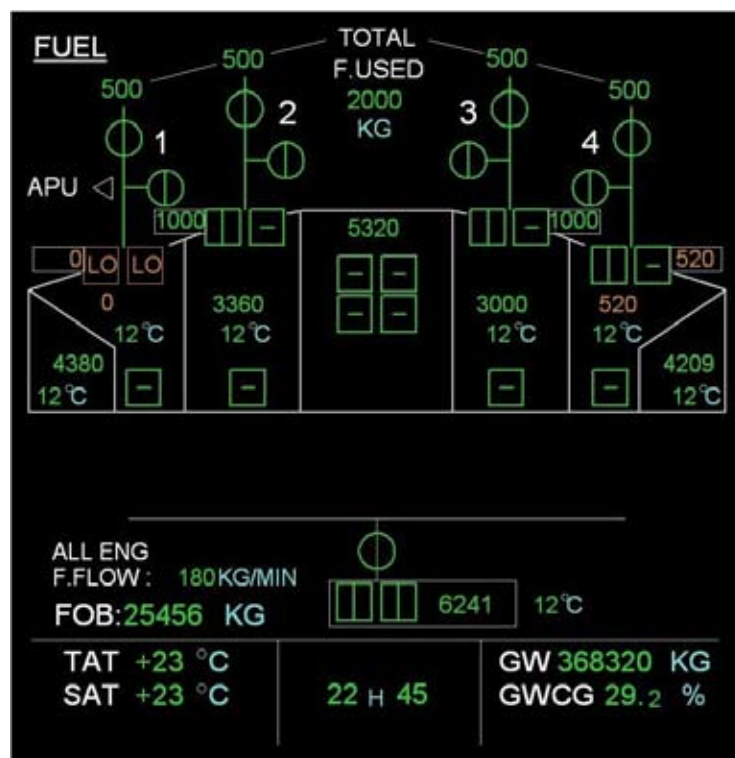
Figure 15

Fuel status page with low fuel pressure on the Inner 1 fuel tank pumps

1.6.12.4   Transfer warnings

If failure of the automatic fuel transfer system is detected, the master FCMC will send an ARINC 429 signal to both FWCs to trigger the relevant warning. All of the transfer warnings are classed as level 2 and result in: the illumination of the master caution light, a single aural warning chime, the fuel status display will appear on the SD. Also, the fault message and crew procedure will be displayed on the EW/D and the 'FAULT' light in the associated manual transfer switch, on the overhead panel, illuminates to identify to the flight crew that manual fuel transfer, using that switch, is required.

The table below shows the related warnings for each transfer fault:

Fault	Switch Fault Warning	ECAM Display in Amber.
Trim tank transfer failure	T TK XFR switch FAULT light illuminated.	FUEL T TK XFR FAULT
Centre to inner tank transfer failure	CTR TK TO INR TK switch FAULT light illuminated.	FUEL CTR/INR XFR FAULT
Outer to inner tank transfer failure	OUTR TK XFR switch FAULT light illuminated	FUEL OUTR TK XFR FAULT

1.6.12.5   Transfer memos

Whilst automatic fuel transfers take place, the master FCMC sends an ARINC 429 signal to the FWCs for the display of an advisory memo, in green, on the EW D. These memos indicate whether fuel transfer is in progress or completed.

Advisory Message in Green	Meaning
T TK XFR IN PROGRESS	Trim tank fuel is being transferred.
T TK XFRD	The trim tank is empty following a forward fuel transfer.
OUTR TK XFR IN PROGRESS	Fuel is being transferred from the outer fuel tanks into the inner fuel tanks.
OUTR TKS XFRD	The outer tanks are empty following the transfer of their fuel into the inner fuel tanks.

1.6.12.6   FCMC/FDC faults

1.6.12.6.1   FCMC1(2) fault

The display of 'FCMC1 (2) FAULT' on the EW/D is an indication that the particular FCMC has failed. There are two ways the FWCs can determine this. Firstly, if the master FCMC detects that it has a fault or that the slave FCMC is faulty, the master FCMC will send an ARINC 429 signal, on both its buses, to the FWCs.

Secondly, both FWCs monitor the ARINC 429 bus inputs from the FCMC. If the ARINC bus does not refresh itself for more than 5 seconds, such as when the ARINC bus is disconnected, then the FWC will fault the FCMC related to the faulty bus it is monitoring.

In both cases the fault is level 1 so the only indication to the flight crew is the display of the 'FUEL FCMC1(2) FAULT' message on the EW/D and the fuel system page on the SD. There is no aural warning. If the fault message is cleared then the message FCMC1(2) is listed under 'INOP SYS' on the status page display of the SD. Appendix F shows the crew procedure for a 'FCMC1(2) FAULT'

If one FCMC has failed, and the remaining FCMC then fails, the FWC will display the 'FUEL FCMC1+2 FAULT' message on the EW/D. This is a level 2 fault, accompanied by the master caution light illuminating and a single chime from the aural warning. The failure of both FCMC1 and FCMC2 means that there is no longer any automatic control of the fuel system or display of fuel quantity. Therefore, the flight crew have to follow a procedure to carry out manual fuel transfers and to estimate the fuel on board (see text of Appendix F).

Having detected a failure of both FCMCs, the DMC uses information from the SDAC for the display of valve and pump status on the fuel system display. In addition, the FWC takes information from the FDC for low fuel level warnings.

1.6.12.6.2   FDC 1(2) fault

If the master FCMC detects that either of the FDCs are inoperative it will send an ARINC 429 signal to the FWCs to display the 'FDC 1(2) FAULT' on the EW/D and display the fuel system page on the SD. This is a level 1 warning, so there is no associated aural or master caution warning. Appendix F shows the crew procedure for an 'FDC 1(2) FAULT'.

When the flight crew clear the fault from the EW/D, the SD displays the message FDC 1(2) under INOP SYS on its status page. On removal of the FDC fault ARINC signal from the master FCMC, the FDC 1(2) message will clear from the INOP SYS listing on the SD status page.

1.6.13   Central maintenance computer

The Central Maintenance Computer (CMC) is the hub of the aircraft's maintenance system and it assists in the diagnosis of faulty systems. Each aircraft system has built in test equipment (BITE) used to test the components and detect faults, and to confirm system operation following remedial actions. Each of the aircraft's systems communicates with the CMC, and transmits to it information on detected faults and any warnings indicated to the flight crew.

With the aircraft on the ground, maintenance staff can access the CMC via a Multipurpose Control and Display Unit (MCDU) on the flight deck and obtain information pertaining to the most recent flight or previous flights. They can also interrogate the BITE information from the various aircraft systems and initiate tests of those systems through the same interface.

Classification of each aircraft system BITE fault, relayed to the CMC, allows grouping of faults depending on their severity. These fault classifications are:

Class 1 failures   These are failures which have a direct effect on the operation of the flight and have been indicated to the flight crew. These include failures which result in a failure message on the EW/D, or warning flags on the crew displays.

Class 2 failures   These are failures which do not have a direct effect on the operation of the flight but may have an effect if there is a subsequent fault. These include failures which are indicated by ECAM after the flight has been completed and the engines have been shut down.

Class 3 failures   These failures have no effect on the operation of the aircraft and are not indicated to the flight crew.

The aircraft systems detect faults in two ways: either internally by the system self-testing its operation, or externally by another aircraft system BITE which uses information from the affected system. For example a fault with an FCMC would be an internal fault if it was detected by the FCMC, but it would be an external fault when detected by the FWCs or the DMCs, which receive information from the FCMC.

The CMC produces various reports which are accessible through the MCDU when the aircraft is on the ground. These reports include the Post Flight Report (PFR), produced and printed at the end of the flight, which contains fault information received from aircraft system BITE and sent to the CMC during the flight. The format of the report is in three columns. The first column 'COCKPIT EFFECTS' shows those faults which resulted in a warning or fault display to the flight crew. The second column provides the time in UTC and the phase of flight when the first fault was detected. The third column lists the information pertaining to the fault such as the ATA reference[2] the class of fault, the source and identifying system and the affected unit.

When the CMC produces the PFR at the end of the flight, to assist the maintenance staff, it carries out some correlation functions between the warnings provided by the FWC and the fault data provided by the aircraft system BITE.

The first correlation function occurs in real time, when the CMC receives a fault detected by the BITE of a system; it stores the information pertaining to the ATA reference, the class of fault, whether the fault is hard or intermittent and the unit which detected the fault (the source). After receiving the fault, the CMC opens a correlation window for one minute and associates with that fault, the names of any additional units which have detected faults with the same first few ATA reference digits. The names of these units are listed in the identifiers field and only the first six are listed, those received after the first six are discarded. If one of the additional faults is class 2 then an asterisk is placed before the identifier name. In this manner only the first fault within a group of similar ATA references received in a one minute window is displayed on the PFR. Any remaining faults relating to the ATA reference is only indicated by the unit names under the identifier. This condenses several faults associated with one ATA reference into just one report.

The CMC carries out a second correlation function when the report is requested which involves associating the warnings received by the FWC with the received BITE faults. This is carried out using the first few ATA digits of the warning from the FWC and the received fault. The correlation can only take place if the warning and the fault are received within a two-minute window. If the warning is a class 1 warning then the correlation function will only associate a fault which is detected as class 1. Similarly if the warning is a class 2 maintenance status warning then the correlation will only associate a class 2 fault with the warning.

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2   The Air Transport Association established standard identifiers for all aircraft systems, based on a 'chapter' numbering system. This nomenclature is used in maintenance manuals and other aircraft documentation.

If the warning is intermittent and recurs several times during the flight, the PFR will only show the first occurrence of the warning and gives no indication of the number of occurrences. In a similar manner, the PFR only shows the first occurrence of a fault in any one flight.

Because the PFR only shows a summary of the warnings and faults, further interrogation of the individual BITE memory on the affected units is required. This is carried out via a MCDU. Reports from the BITE memory, in the form of troubleshooting data, can be accomplished and the reports printed.

1.6.14   Operating procedures and manuals

Aircraft operating procedures for flight crew are laid out in the Flight Crew Operating Manual (FCOM). Abnormal and emergency procedures are primarily displayed on the ECAM. Expanded information may also be available in the FCOM which the crew should review if there is time available. For a failure which does not generate an ECAM message, the crew may be able to refer to procedures in the QRH and/or to the FCOM. The A340-600 FCOM contained 26 pages of fuel system abnormal and emergency procedures.

1.6.15   Engine failure operational procedures

Engine failure generates an ECAM alert with an associated crew procedure. An expanded version of the ECAM procedure is provided in the FCOM (see Appendix G).

The Abnormal Procedures section of the A340-600 QRH contains a section for relighting an engine in flight (see Appendix H).

1.7   Meteorological information

There was no en-route weather of any significance to this incident. The Amsterdam Airport weather conditions passed by ATC to the crew were: surface wind variable at 2 kt, visibility 5 km in mist, sky clear, temperature +4ºC, dewpoint -6ºC and QNH 1026 mb.

1.8   Aids to navigation

Not applicable.

1.9 Communications

Recordings of the transmissions between the aircraft, Maastricht ATC and Amsterdam ATC were available for the investigation. After the flight crew declared a MAYDAY they were issued a dedicated frequency by Amsterdam ATC which was retained in use until after the aircraft had landed.

1.10 Aerodrome information

Not applicable.

1.11 Flight recorders

1.11.1 General

The aircraft was equipped with a Flight Data Recorder (FDR)[3] and a Cockpit Voice Recorder (CVR)[4], as per regulation[5]. The FDR recorded a range of both digital and discrete flight parameters for a minimum duration of 25 hours and the CVR[6] recorded the last two hours of audio data from the flight deck environment.

Both the FDR and CVR were successfully replayed at the AAIB. FDR data was available for the entire incident flight and the two-hour CVR had recorded about 70 minutes of data prior to the landing, with the data commencing about 30 minutes before the run down of the No 1 engine.

The aircraft was also equipped with a Quick Access Recorder (QAR). However, the QAR was not recording at the time of the incident because the recording media had been filled to capacity prior to the incident. The QAR recorded the same data as the FDR so it would not have provided any additional data.

1.11.2 Flight Data Recorder and Cockpit Voice Recorder

Relevant parameter from the recorded flight data are presented in graphical form in Figures 1, 2 and 3 at Appendix I.

Quotations from the CVR are in "*ITALIC CAPITAL LETTERS*". Times quoted are UTC recorded times acquired from the aircraft's clock data bus.

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3   Honeywell manufactured Solid State Flight data Recorder (FDR), Part Number 980-4700-042.
4   Honeywell manufactured Solid State Cockpit Voice Recorder (CVR), Part Number 980-6022-001.
5   JAR-OPS 1 Subpart K.
6   The CVR recorded four channels of audio whenever the CVR was electrically powered.

The aircraft commenced taxiing at about 1558 hrs. Whilst taxiing, at 1615:29 hrs, an FCMC1 fault[7] was recorded for a period of four seconds. There were no further recordings of an FCMC1 fault for the remainder of the flight and there were no recordings of an FCMC2 fault at any time during the flight.

Takeoff occurred at about 1621 hrs with a total recorded fuel quantity of 135,400 kg[8]. Shortly after takeoff an autopilot was engaged. The aircraft climbed and when it was at about FL250 the trim tank quantity started to increase (see Appendix I, Figure 1, Point A). The aircraft continued to climb until it reached about FL335 at about 1655 hrs. By then the trim tank quantity had stabilised at about 6,280 kg (Figure 1, Point B).

At about 1928 hrs at FL354, the centre fuel tank quantity stabilised at about 5,312 kg (Figure 1, Point C).

The FDR indicated that the Electronic Centralised Aircraft Monitor (ECAM) fuel synoptic page[9] was subsequently displayed on six occasions between about 2100 hrs and 0302 hrs, with the longest duration being about 12 seconds and the shortest less than four seconds. The fuel page was displayed for less than four seconds at 0302 hrs.

At 0328 hrs, at FL380 and at an airspeed of about 264 kt, the INNER 1 fuel tank quantity reduced to zero (Appendix 2, Figure 2, Point A). About 40 seconds later the No 1 engine N_1 parameter decreased and the aircraft yawed (Figure 2, Point B) which alerted the crew to an engine problem. The No 1 engine thrust lever was retarded to the idle position and the numbers 2, 3 and 4 thrust levers were set to the maximum continuous thrust (MCT) detent position. Nevertheless, the airspeed slowly started to reduce.

The flight crew then started to perform the ECAM procedure for engine failure which included the option of re-starting an undamaged engine. They discussed this option but decided not to attempt to restart No 1 engine and subsequently the SHUT DOWN procedure was completed at about 0331 hrs. At that time the Inner 4 fuel tank quantity was about 494 kg and the total fuel quantity was about 26,940 kg[10]. As the flight crew progressed through the

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7   The FDR recorded the fault status of FCMC1 and FCMC2. Both parameters were recorded from the flight warning computer (FWC) at a rate of once every four seconds.
8   A mean value of data before and after the takeoff point as data was not recorded coincident with the takeoff point due to the sample rates of the fuel quantity parameters.
9   The FDR recorded the type of synoptic page displayed on the Electronic Centralised Aircraft Monitor (ECAM) system once every four seconds.
10   The FDR recorded fuel quantities for each of the fuel tanks once every 64 seconds. The FDR fuel quantity parameters were recorded from the Display Management Computer (DMC) system.

ECAM actions, the operating co-pilot read out the inoperative systems from the ECAM status page, during which he said "......AND FCMC TWO THAT WE HAD ORIGINALLY".

The flight crew then started to discuss fuel imbalance and the options of either opening the fuel cross feeds or continuing to monitor the fuel tank quantities. At about 0335 hrs the ECAM fuel system synoptic page was selected. Shortly afterwards the commander said "WHY HAS THAT GONE TO ZERO". The flight crew then started to discuss the possibility of a fuel leak and the commander said "I DON'T THINK THAT WAS A WIND DOWN BECAUSE OF FUEL STARVATION...BUT THERE IS NO FUEL THERE". Subsequently, a crew member was sent aft to inspect the engine and wing for symptoms of a fuel leak but nothing untoward was reported when the member returned to the flight deck.

The fuel system synoptic page was displayed for about 3 minutes between about 0335 hrs and 0338 hrs. The Inner 4 fuel tank quantity was about 230 kg at about 0335 hrs and within about 3 minutes it had reduced to 88 kg. During this period, the flight crew did not refer to the quantities in any of the other fuel tanks.

At about 0340 hrs the Inner 4 fuel tank quantity reduced to zero (Figure 2, Point C). About 25 seconds later the No 4 engine N_1 shaft speed started to reduce (Figure 2, Point D). Within 4 seconds the N_1 shaft speed had reduced from about 80% to about 50%. This time the co-pilot said "ITS NUMBER FOUR" and, almost immediately, the commander said "OPENING THE CROSS FEEDS". Shortly afterwards the No 4 engine N_1 shaft speed started to increase. It continued to increase until it had stabilised at 80% some 11 seconds later. During this time the No 4 thrust lever position remained in the MCT detent position.

The commander then said "THERE'S A FUEL MANAGEMENT PROBLEM". The flight crew then agreed that they would attempt to restart the No 1 engine. If it restarted, they would declare a PAN and proceed to London Heathrow, which was about two hours away, but if it would not relight, they would declare a MAYDAY to ATC and divert. At about 0345 hrs the flight crew attempted to restart the No 1 engine (Figure 2, Point E). The co-pilot was reading out the engine restart procedure, during which he said "ENGINE RELIGHT IN FLIGHT...MAX GUARANTEED ALTITUDE THIRTY THOUSAND FEET". The flight crew proceeded with the restart procedure in level flight at about FL380 but the restart was not successful. At no time during the restart procedure did the crew discuss the aircraft's altitude.

The flight crew discussed the status of the fuel system and that fuel did not appear to be transferring from either the trim or centre fuel tanks. The fuel system's flight deck switch positions were not recorded on the FDR but the flight crew then initiated the following fuel system selections: trim tank transfer set to FORWARD, outer tank transfer to ON, centre to inner left and right were set to OFF and the centre aft transfer left and right were set to OFF. The commander then said "*AND OPEN…. WE HAVE TO DO THAT AS WELL*" which was followed by a noise that was consistent with a switch being set. The flight crew did not refer to which switch was being set at the time. Almost coincident with this action, the centre tank and all four inner fuel tank quantities started to increase and the trim and both outer fuel tank quantities started to decrease (Figure 2, Point F). About this time the co-pilot said "*WE GOT SOME FUEL COMING IN TO… ONE AND FOUR…*". However, at about the same time the commander declared a MAYDAY to Maastricht ATC.

The commander advised ATC that the aircraft had a fuel management problem, that they needed to land as soon as possible, and that Amsterdam would be suitable airport. ATC subsequently provided a clearance to descend from FL380 to FL200 and shortly afterwards the flight crew initiated a descent (Figure 2, Point E). When the aircraft started to descend the airspeed was about 250 kt.

About 20 minutes had elapsed between the No 1 engine rundown and the aircraft starting to descend from FL380. During that period the airspeed had gradually been reducing at a rate of about 1 kt every 90 seconds. The crew did not discuss at any time the gradual reduction in airspeed.

At about 0350 hrs the commander said "*IT ISN'T TRANSFERRING FORWARD… WOULD YOU AGREE WITH THAT*". However at that time the FDR data indicated that the trim tank quantity was slowly reducing at a rate of about 100 kg/minute. The flight crew then referred to a "*TRIM TANK TRANSFER FAULT*" procedure. As they read out the actions, they confirmed that the trim tank transfer was selected to FORWARD and the trim tank feed was selected to OPEN. The flight crew then discussed whether the trim tank feed switch should have previously remained in the AUTO position; one of the crew then said "*SO PUT THAT BACK TO AUTO*". Coincident with this a noise, which was consistent with a switch selection, was also recorded on the CVR. The FDR data indicated that the trim tank fuel quantity was continuing to decrease. At about 0351 hrs air traffic control of the aircraft was passed to Amsterdam ATC who advised the crew of the weather and runway in use at Schiphol Airport, which was Runway 06.

At 0356 hrs the aircraft was descending through FL160. About this time the

commander said he was concerned that fuel was not transferring out of the centre fuel tank to the inner fuel tanks. Subsequently the flight crew referred to a centre inner transfer tank fault procedure, during which they were recorded saying that the centre to inner fuel transfer switch was being set to the MANUAL position. The flight crew then discussed whether the fuel in the centre tank might be unusable if the centre tank quantity was less than 35 tonnes. One pilot then said *"WE DON'T KNOW WHETHER IT'S COMING OUT"*. The flight crew then agreed that they had about 10 tonnes of usable fuel. At the time the total fuel quantity in the four inner fuel tanks was about 9,985 kg and there was a total of about 14,000 kg of fuel in the centre, trim and outer fuel tanks. A short time later the centre tank fuel quantity started to reduce (Figure 2 Point G).

At about 0359 hrs the commander advised ATC that the aircraft would not require any assistance after they had landed. Shortly afterwards ATC control of the aircraft was transferred to Schiphol approach control.

At about 0404 hrs the flight crew had just completed the approach checks and were reviewing the fuel transfer status. One pilot said that fuel was coming out of the centre fuel tank, although another then said that the fuel was coming out of the trim tank and that the centre tank fuel was unusable. However, the FDR data indicates that both the trim and centre fuel tank quantities were reducing at the time.

The flight crew had not referred at any time during the cockpit voice recording to making a record of the fuel tank quantities.

At about 0408 hrs the autopilot was disengaged at about 2,100 ft amsl and the aircraft had been fully configured for landing. The commander subsequently performed a manual landing, with touchdown occurring at about 0410 hrs.

The total fuel quantity at touchdown was 22,961 kg. The fuel quantities for the number one through four inner fuel tanks were 2,641 kg, 5,922 kg, 5,370 kg and 2,584 kg respectively. The centre fuel tank quantity was 4,325 kg and the trim tank fuel quantity was 2,119 kg. Both of the outer fuel tanks were empty.

As the aircraft taxied from the runway, ATC were advised by the crew that they were cancelling the MAYDAY and that they would not require the emergency services. The commander subsequently advised the airport fire services that they did not have a fuel leak and that there was no risk of fire. The aircraft came to a stop on stand G9 and the engines were shutdown at about 0429 hrs. The FDR stopped recording at 0433 hrs.

1.11.3   Normal fuel transfer

The aircraft manufacturer provided data that reflected normal fuel transfer. The graph at Appendix I Figure 3 illustrates fuel quantities during the incident flight plotted against normal fuel transfer data. It should be noted that due to variances in fuel burn between the manufacturer's data and the incident flight, 8,900 kg/hour against the average fuel burn of about 9,500 kg/hour respectively, the individual tank quantities do not track one another exactly, but they do typify the normal transfer of fuel from both the trim and the centre fuel tanks. The data was aligned so that the total fuel quantities were within 50 kg when G-VATL entered the cruise phase.

1.12   Post-incident aircraft examination

1.12.1   Aircraft examination in Amsterdam

On arrival at Amsterdam, the aircraft's Central Maintenance Computer (CMC) 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 No 1 engine. A manual refuel was carried out and the aircraft was flown on a non-revenue flight to Heathrow.

1.12.2   Aircraft examination at Heathrow

The aircraft was examined after its arrival at Heathrow. 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 FDCs, the FWCs and the SDACs 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.

1.12.3   FCMCs Examination

The details of the FCMC computers removed from G-VATL were:

FCMC1 Part Number   367-327-002
FCMC1 Serial Number   87-1074
FCMC1 Software Load   Flight Load 7
FCMC2 Part Number   367-327-002
FCMC2 Serial Number   87-1106
FCMC2 Software Load   Flight Load 7

Both FCMCs were taken to the component manufacturer. The internal memory of each unit was downloaded, after which the units were placed on the manufacturer's development test bench for further tests together with the removed FDCs.

The FCMC troubleshooting data (TSD) related to the incident flight is shown at Appendix J.

Following the development bench-tests, the FCMCs were subjected to the normal manufacturers specified acceptance test; both FCMCs passed. After this each unit was vibration and environmentally tested, before being examined visually for signs of foreign objects or mechanical damage. Both FCMCs passed all of these tests.

1.12.4   FDCs Examination

The details of the FDC computers removed from G-VATL were:

FDC 1 Part Number   367-328-003
FDC 1 Serial Number   58-1068
FDC 2 Part Number   367-328-003
FDC 2 Serial Number   58-1070

The FDCs were taken to the component manufacturer for further testing. The FDCs did not contain any non volatile memory so, following some testing on the manufacturers development test bench together with the FCMCs, the units were subjected to their manufacturer's acceptance tests. These tests were all satisfactory for both units. In addition, the computers were subjected to environmental and vibration testing which again did not reveal any defects. Lastly, each unit was stripped and examined in detail for signs of foreign objects or mechanical damage; none was found.

1.12.5   FWCs Examination

The details of the FWC computers removed from G-VATL were:

FWC1 Part Number   LA2E0060CW30000
FWC1 Serial Number   2E0002367
FWC2 Part Number   LA2E0060CW30000
FWC2 Serial Number   2E0002060

Initially an attempt was made to download the troubleshooting data (TSD) in the memory of each FWC, but the test facility in use was not able to interpret this data and produce a real time translation. However, the data was retrievable in its raw state and so later it was manually converted to a readable state.

The TSD data from the FWC relevant to the incident flight was:

Date and UTC	Detecting Unit	Detected Failure	Detected Occurrences in Flight	Type of failure	Failure origin - Unit	Due to	ARINC label
07 FEB – 16:55	FWC1	External Failure	2	Arinc Bus	FCMC/2	No Refresh	154-2
07 FEB – 16:55	FWC2	External Failure	2	Arinc Bus	FCMC/2	No Refresh	153-2

Later, following fault testing described in section 1.16 below, the FWCs were fully tested against using the manufacturer's acceptance test procedure. Both FWCs passed with no failures being reported.

1.12.6   SDACs examination

The details of the SDACs removed from G-VATL were:

SDAC 1 Part Number   LA2E07000000C7
SDAC 1 Serial Number   2E5002338
SDAC2 Part Number   LA2E07000000C7
SDAC2 Serial Number   2E5002330

The TSD data from each SDAC was retrieved, with a real time translation of the data. There were no faults on the TSD for either SDAC which were relevant to this investigation.

Later, following fault testing described in section 1.16 below, the SDACs were fully tested against using the manufacturer's acceptance test procedure. Both SDACs passed with no failures being reported.

1.12.7   DMC Data Download

The DMCs were not removed from the aircraft but the troubleshooting data contained in the non-volatile memory of each of the three computers was downloaded. Later tests conducted on the DMCs were all satisfactory.

A copy of the decoded data from the DMC TSD related to the incident flight is shown below in Appendix K.

1.13   Medical and pathological information

Not applicable to this investigation.

1.14   Fire

There was no fire.

1.15   Survival aspects

Not applicable to this investigation.

1.16   Tests and research

1.16.1   Additional FCMC and FDC tests

Following the download of the FCMCs' memory, the FCMCs and FDCs removed from G-VATL were installed onto the manufacturer's development test bench. This enabled various scenarios to be examined including the automatic fuel transfer operation and responses to various faults. Lastly, the test bench enabled the running of a virtual flight, similar to the incident flight, to ensure that the FCMCs correctly commanded the automatic fuel transfers over a representative time scale.

In all the tests carried out, both FCMCs provided the correct responses and commanded fuel transfers in the correct sequence and at the right times.

Faults were then injected into the FCMCs to ensure that they identified the fault and then transferred control as required. The first tests were to inject failures of various valves and pumps with FCMC1 as master. In this scenario FCMC1

correctly sent out transfer warnings on its ARINC output buses and FCMC1 was also failed with transfer of master control to FCMC2. FCMC2 then indicated the same faults on its ARINC output buses. The same test with FCMC2 as master also resulted in transfer warnings on the ARINC buses and transfer of control to FCMC1.

The next set of tests involved degrading the health of FCMC2 with FCMC1 set as master. The health was degraded by failing the FCMC2 discrete output function and the ARINC output bus A wrap. The result was FCMC2 immediately detected the failure, FCMC1 also indicated a failure and FCMC1 remained as master at health level 5.

The same test was conducted with health degradation of FCMC2 but with FCMC2 as master. Again FCMC2 immediately failed itself and master control transferred to FCMC1. Two minutes later FCMC1 failed itself and FCMC2 regained master control only to fail again two minutes later; FCMC1 became and remained master at health level 5. In all cases the FCMC failures were all reported on the ARINC output buses of both FCMCs and would have resulted in the 'FCMC1+2 FAULT' warning on the EW/D display.

The final test of running a virtual flight resulted in the correct operation of fuel transfers with all the fuel being fed to the engines with no reported problems.

1.16.2   Additional FWC and SDAC tests

The FWCs and SDACs removed from G-VATL were installed on the manufacturer's development test bench. This enabled testing of the functionality of the units, through the injection of simulated warnings on the ARINC input buses into the FWCs, and the monitoring of the outputs from each FWC.

In the first instance, signals relating to fuel transfer and fuel low level were injected into the FWC, as though they originated from the FCMCs. In each case the FWCs provided the correct warning response.

The next test involved disconnecting FCMC2 ARINC BUS A input into FWC1. Following the disconnection, FWC1 detected the failure of the ARINC input line and responded with a FCMC2 fault. Fuel low level signals were then injected as though they originated from FCMC2. FWC2 detected the low fuel level warning, sounded the aural warning and illuminated its commanded half of the master caution lights. Similar tests were carried out with a disconnected FCMC1 ARINC BUS A input, with a similar result from FWC1.

With both FCMCs indicating they were operational, the discrete inner tank fuel low level inputs, which originate from the FDCs, were simulated. As expected, in each case the low level warnings were not displayed by the FWCs, as they would have detected that the FCMCs were still operational.

To simulate a failure of both FCMC1 and FCMC2, all the FCMC ARINC input buses to the FWCs were disconnected. This resulted in the FWCs failing both the FCMCs and displaying the 'FCMC1+2 FAULT'. When the simulated FDC inner tank low fuel level discrete were set, the relevant 'INR 1 (2 3 4) LO LVL' warning was triggered by both FWCs.

Lastly, FCMC2 ARINC BUS A and B inputs were disconnected from the FWCs with the FCMC1 ARINC inputs still active. The FWCs correctly faulted FCMC2. When signals were injected on the ARINC buses as though FCMC2 was the master FCMC, no warnings were generated by the FWC. However, when the same signals were sent on the FCMC1 ARINC input buses, in each case the FWCs produced the relevant warning message, aural warning and master caution annunciation.

1.16.3   Component manufacturer scenario testing

Immediately following the incident, the fuel control system manufacturer conducted bench tests with development FCMCs and FDCs to try to replicate the events seen during the incident flight on G-VATL.

The tests included shorting-out the discrete outputs to valves and pumps, all of which were detected by the FCMC. Because the incident may have been due to an internal fault, various failures were induced on the COM, MON, ICP and other circuitry within the FCMC. In all cases the FCMC detected and reported the induced faults.

A simulation was then set up on the development test bench, with development FCMCs and FDCs, using data from the incident flight and the BITE data from the computers fitted to G-VATL at the time. Initially, only the ARINC and discrete health mismatch was simulated. Firstly, FCMC1 was set as master and FCMC2 was failed with the ARINC and discrete health mismatch; in this case FCMC1 remained as master. In the second case, FCMC1 was set as master again but with the faults on ARINC and discrete health mismatch failed on FCMC1. In this scenario FCMC1 remained as master, but FCMC2 tried to take control with the master/slave status repeatedly switching between both units.

A scenario was then set up with the fuel status set to replicate that on G-VATL at 1930 hrs during the incident flight. FCMC1 was set as the slave and its health degraded to level 5, with FCMC2 set as the master. A discrete health mismatch, an ARINC A output wrap failure and a total discrete output board failure were set on FCMC2. Following the setting up of the failure, FCMC2 reported an 'FCMC2 FAULT' on both its ARINC output buses but remained as master FCMC. Also, the centre to inner transfer fault was set by FCMC2. The fuel levels were depleted and when the outer tank transfers should have taken place, the outer tank transfer warning and valve failures were set by FCMC2. When the fuel in the inner tank reached the low-level quantity, the COM and ICP set the low-level warnings and the FDC low-level discrete also triggered.

1.16.4   MSN 360 trials

The two FWCs, the two FCMCs and the two FDCs removed from G-VATL, following the incident, were fitted to the development A340-600 MSN[11] 360. The intention was to fly the aircraft with the components fitted so that if the fault was to occur again, the additional parameters that are recorded on MSN 360 would enable a fuller understanding of the possible root cause.

The units were fitted to MSN360 for a total of 38 flights, which amounted to about 95 flying hours. During these tests either FCMC 1 or FCMC 2 remained in control and correctly commanded the fuel transfers, in addition all the FWC presented the expected fuel warnings. FCMC fault messages did occur during the flights and were mostly related to the known problem with COM/MON disagrees, explained in parts 1.18.4 and 1.18.11 of this report.

On one flight, however, there was a significant failure of FCMC2 and was related to its DOUT, causing the unit to cut off its ARINC outputs. In this circumstance FCMC1 correctly took control as master.

1.16.5   Hypothetical fuel display if only slave FCMC is supplying DMC

Figure 16 shows a hypothetical reconstruction of the fuel status page. The reconstruction was based on the situation of a total failure of the master FCMC outputs on its discrete and ARINC output lines, and the slave FCMC remaining as the slave but with functional ARINC and discrete outputs. It was not possible to recreate the scenario on a representative aircraft, so the only way to recreate the SD page was by hypothesis and the use of the logic system within the DMC.

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11   (Aircraft) Manufacturer's serial number.

The DMC normally receives data from the master FCMC for the display of the fuel system status on the SD. However, in this situation, the DMC is not receiving any data from the master FCMC and so it selects the SDAC as the data source for the status of the centre tank fuel pumps, main and standby engine fuel pumps, trim tank fuel pumps, engine LP fuel valves, cross feed valves, cross feed pipe and jettison system. Although fuel quantity data is available from the slave FCMC, it is presented without the amber warnings of low contents in the collector cells and the tank, which can only be generated by the master FCMC. Also, without data from the master FCMC, the fuel transfer arrows would not be displayed when fuel transfer was taking place. However, in this scenario, the engine fuel pump and standby engine fuel pump low pressure data to the DMC is provided by the SDAC. Therefore, an amber LO indication should have been displayed on the fuel page for the number 1 main and standby pumps.

Figure 16

A hypothetical interpretation of the display presented to the flight crew on G-VATL

Figure 17

Interpretation of what the flight crew should have seen at the engine rundown

In comparison the display that should have been shown with a fully functional master FCMC is shown in Figure 17.

The symbology that should have been presented with a fully functional master FCMC is illustrated in Figure 17. Comparison of the two displays illustrates that failure of the outputs from the master FCMC, but with the slave FCMC still providing data, results in suppression of the amber tank and collector cell quantity indications as shown in Figure 16.

1.16.6   Significant previous fuel management incidents in Airbus aircraft

On the 24 August 2001 an Airbus A330 aircraft made an all-engines-out landing at Lajes, Azores, due to fuel exhaustion following a fuel leak. As a result of the investigation a number of safety recommendations were made concerning the fuel system on the aircraft.   One of these recommendations was:

Safety Recommendation AD2004: That as an interim measure all civil aviation authorities promulgate the circumstances of this fuel leak event to all air operators, aircraft manufacturers and flight crew training organisations.

As a result of this event, flight crew awareness in recognition and management of fuel leak detection and procedures was enhanced. A number of changes were made to flight training programmes, to give flight crew training in fuel leak scenarios. Changes were incorporated into the ECAM fuel procedures and to the FCOM procedures for all Airbus aircraft.

1.17   Organizational and management information

1.17.1   Operator

The airline held an Air Operator's Certificate (AOC) issued by the UK Civil Aviation Authority. The company operated a mixed fleet of aircraft employed on scheduled passenger services on international routes.

1.17.2   Published operational information.

The aircraft manufacturer provided an FCOM for the aircraft. Amendments, Temporary Revisions (TR) and Operations Engineering Bulletins (OEB) were added to the FCOM by the manufacturer as required. Any further required Standard Operating Procedures (SOP) or information were provided in Operations Manuals and updated by the operator. The operator also provided crew information in the form of 'Company Notams' and 'Notices to Aircrew' for short duration changes or changes not yet incorporated in the Operations Manuals.

1.17.3   Airbus company structure and design philosophy

Airbus was formed in 1970 as a consortium of European aerospace manufacturers. The overall design of Airbus aircraft is carried out primarily by Airbus's central design office in Toulouse, France. However, the design of some aircraft systems and components is distributed amongst four main centres: Airbus France, Airbus UK, Airbus Deutschland and Airbus España.

Airbus UK has design responsibility for the fuel system and the wings whereas Airbus France has design responsibility for the cockpit displays and avionics including the flight warning system.

Each regional centre produces the design specification and the interfaces between the systems. Therefore, Airbus France provided Airbus UK with a specification for the generation of fuel system warnings and displays.

Similarly, Airbus UK produced the design specification for the fuel system. This specification was then passed to a US based sub-contractor for the design and manufacturer of the fuel system components. Included in the specification were details of the outputs required for the display of fuel quantity and the provision of fuel warnings.

Although one design office is aware of the design work of another office, the detailed information is contained within each individual office. This means that information regarding the flight warning system, central maintenance and flight displays is available only from Airbus France and similarly, information regarding the fuel system design is available only from Airbus UK.

The interface between the two design areas is usually accomplished through the use of specification documents and discussion meetings.

1.18 Additional Information

1.18.1 Previous sector observation

The flight crew that operated the previous sector inbound to Hong Kong were contacted and asked whether they had experienced any fuel system abnormalities during that flight. The commander recalled that they had observed a degree of wing tank fuel imbalance which, although it was not sufficient to generate an ECAM advisory, he considered unusual. He commented that some imbalance was normal but the differential on this flight was more than was usually seen and so they continued to monitor the system. As a precaution, all the fuel cross feeds were opened before commencing the descent into Hong Kong.

1.18.2 Post Flight Report (PFR)

Appendix L shows the PFR for the flight from Hong Kong to Amsterdam. Those items relating to the fuel system have been decoded as showing the following:

At 1621 hrs during climb a warning 'FUEL FCMC2 FAULT' was displayed in the flight deck. At the same time both FCMC1 and FCMC2 BITE had detected ATA 28[12] class 1 faults, the first of which was a hard fault relating to the inner 4 tank temperature sensor. There were no class 2 faults detected during the minute following the first fault.

At 1626 hrs during cruise a warning 'FUEL FDC 2 FAULT' was displayed in the flight deck. At the same time, the CMC received detected ATA 28 faults from FCMC1 and FCMC2 BITE, the first of which was a hard fault relating to FDC 2. Again there were no class 2 faults detected during the minute following the first fault.

At 1934 hrs during cruise the class 2 maintenance status FCMC1 was displayed. At the same time the CMC received additional ATA 28 faults from FCMC1, the first of which was a class 1 hard fault with the 'FUEL TRIM TK ISOL VALVE'. An asterisk against FCMC1 indicates that at least one additional fault in the one minute correlation window was a class 2 fault. Because the first fault was a class 1 fault and the warning displayed to the crew can only be related to a class 2 fault, there is no fault/warning correlation. Consequently, the fault information is displayed in its own row, below the original warning.

Appendix M shows the PFR for the previous flight from Sydney to Hong Kong and the information relating to the fuel system has been decoded below:

At 0530 hrs during cruise a class 1 fault with fuel inner 4 tank temp sensor was detected by FCMC2. In the minute following the first fault additional ATA 28 faults were received by the CMC from FCMC1. There were no related ATA 28 warnings at the same time.

At 0531 hrs during cruise the warning 'FUEL FCMC2 FAULT' was displayed to the crew. At the same time the CMC received a hard class 1 fault with FCMC2 detected by FCMC2. There were no additional ATA 28 faults from FCMC1 during the minute following the fault.

At 0534 hrs the CMC received a class 1 intermittent power supply interrupt fault from FCMC2, with additional faults relating to the same ATA from the FWS in the minute following the fault.

At 0604 hrs during cruise the warning 'FUEL FCMC1+2 FAULT' was displayed to the crew. At the same time the CMC received a hard class 1 fault related to FCMC1 which was detected by FCMC1 (Ie FCMC1 detected its own failure

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12   ATA Chapter 28 is the Fuel System.

and signalled that to the CMC). There were no additional ATA 28 faults from FCMC2 during the minute following the fault.

Also at 0604 hrs the warning 'FUEL T TK PMPS FAULT' was displayed to the crew, with no associated faults within ATA 28.

At 0610 hrs the warning 'FUEL T TK XFR FAULT' was displayed to the crew. At the same time the CMC received a class 1 intermittent power supply interrupt fault from FCMC1, with additional faults relating to the same ATA from the FWS and DMC3 in the minute following the fault.

1.18.3   Aircraft technical log and previous PFR

A review of the technical log book for G-VATL was carried out for the period between 1 January 2005 and the incident on 8 February 2005. This revealed several entries for 'FCMC1 FAULT', 'FCMC2 FAULT' and 'FCMC1+2 FAULT'. Whenever this was reported in the technical log, a test of the FCMC was reported as being satisfactory. However, on 17 January 2005 there were entries for 'FDC 2 FAULT', and 'FCMC2 FAULT'. The troubleshooting showed the problem to be due to the Inner 4 fuel tank temperature sensor. A subsequent test of the fuel system was carried out satisfactorily. Following this, on 23 January 2005, reports were made of fuel low temperature readings for the Inner 4 fuel tank. A deferred defect was raised to replace the temperature sensor and it was replaced on 5 February 2005.

The operator maintained a database of PFR contents which was interrogated for previous reported fuel system problems on G-VATL arising on or after 1 November 2005. This search also revealed several cases of 'FCMC1 FAULT' and 'FCMC2 FAULT', some of which were not reported in the corresponding technical log report. In the majority of cases where a FCMC fault was reported on the PFR, there was also a corresponding power interrupt indicating an in flight reset of the unit. According to the PFR reports, Inner 4 tank temperature sensor was first reported as being defective on 30 January 2005, with increasing frequency of reports up to the event on 7 February 2005.

The only other PFR of note was for a flight on 15 January 2005. During the flight there was a 'FCMC2 FAULT' with a subsequent power supply interrupt indicating a reset of the FCMC. Some three hours later, the 'FUEL INR 1 LO LVL' was reported. There was no corresponding entry to reflect these events in the technical log and no troubleshooting was carried out.

1.18.4   'FCMC1(2) FAULT' event frequency.

At the time of the incident it was reported that the A340-600 cockpit indication of an 'FCMC1(2) FAULT' was quite prevalent and was associated with the standard of system software. To quantify the extent of the FCMC fault reports, the PFR database was interrogated to produce the cases of reported FCMC faults for all the A340-600 aircraft in the operator's fleet. The table below shows the results of this analysis:

Aircraft	Percentage of Flights with FCMC faults reported on the PFR between 1 Nov 2004 and 7 Feb 2005
G-VATL	45.14%
G-VSHY	37.84%
G-VOGE	39.66%
G-VMEG	47.40%
G-VFOX	53.61%
G-VEIL	23.68%
G-VGOA	26.67%
Average	39.14%

The aircraft manufacturer was aware of the problem and had issued a Technical Follow Up (TFU) to operators to make them aware that the issue was under investigation. TFU 28.51.00.018 was first issued in September 2002; in January 2005 issue 10 had been released with the next update being due in March 2005.

The TFU stated that:

'FCMC faults (1 or 2) are caused by FCMC COM and MON (command and monitoring) channel disagreement when monitoring fuel valve position or pump status during fuel transfers'

The TFU provided the following maintenance advice:

'When FCMC1(2) FAULT or FCMC1+2 FAULT are reported; it is recommended to perform a test of the involved FCMC through the MCDU to confirm FCMC serviceability.

If further faults (CTR/INR PUMPS fault, TRIM TK XFR fault…) are shown on the PFR, check the FCMC bite for fuel system component failure. If the operational test of the involved component(s) is (are) successful, no maintenance action is required'.

The TFU mentioned that the reason for the nuisance FCMC faults was due to a COM and MON disagreement. The MON carries out a monitor function of the COM within the FCMC, ensuring that the COM is correctly commanding the fuel system valves and pumps. If the MON detects that the COM has not provided the correct command within a certain period of time, it will fail the FCMC; indicated by an 'FCMC1(2) FAULT' message. The COM and MON boards have their own separate internal clocks, independent inputs and algorithms which are not synchronised. This leads to the COM and MON becoming asynchronous and the MON may determine a different command conclusion to the actual command from the COM, resulting in the MON failing the FCMC.

Solutions for these nuisance faults were attempted in Flight Loads 6 and 7 but without success. An effective solution was expected in Flight Load 8.

1.18.5   Flight crew advice following an FCMC Fault.

The following information was contained in an Operator's Notice to Aircrew 8/05 (a re-issue of 48/04):

'FCMC faults are fully understood by VAA and Airbus, therefore during flight if you experience a SINGLE FCMC FAULT ECAM caution and it can be cleared by a single reset there is NO requirement for flight crew to raise an entry in the technical log.'

1.18.6   Inner 4 tank temperature sensor faults

According to the PFR the first report of the Inner 4 tank temperature sensor being faulty was on 30 November 2005. The technical log shows report of problems with the Inner 4 fuel tank temperature indication from 23 January 2005 and a deferred defect for rectification action in the future, being raised on 27 January 2005. The sensor was replaced on 5 February 2005. However, as seen in the PFR for the event, the fault remained.

On 27 February 2005, the Inner 4 tank temperature sensor was swapped with the Inner 1 tank temperature sensor. Since this rectification work there has not been a repeat of the fault. It is suspected that the removal and reseating of the electrical connections during the sensor swap cured the problem.

1.18.7   Engine restart capability

Following the rundown of No 4 engine and the opening of the fuel cross feed valves by the flight crew, a relight of engine No 1 was attempted at FL380. The crew carried out the QRH checklist items to start the No 1 engine, but its N3 (HP Spool) speed reached only 19% before the compressor stagnated and the start procedure was terminated. However, once the aircraft was on the ground, the engine was started normally and did not exhibit any problems with its operation.

During certification testing, FL350 was the highest level at which the engine would successful relight. This level is 3,000 feet lower than the altitude of G-VATL during the attempted relight.

In the Abnormal Procedures section of the A340-600 QRH there is a section for 'ENG RELIGHT (in flight)' (see Appendix H) which states:

'MAX GUARANTEED ALTITUDE………………30000 FT'

The FCOM provides a procedure for the ECAM message ENG 1 FAIL (see Appendix H) which includes a procedure for relighting an undamaged engine but it makes no mention of any altitude restriction.

1.18.8   Time Line

Appendix N shows a time line of the events, with information gathered from the FDR, CVR, crew interviews, FCMC TSD, FWC TSD, DMC TSD and the PFR.

1.18.9   Fuel system regulations

1.18.9.1   Large aeroplanes

A review of the current European (EASA) certification requirements 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

For all aeroplanes

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."*

1.18.9.2   Normal, Utility, Aerobatic, and Commuter category aeroplanes

A review of similar requirements for other, smaller aeroplanes and rotorcraft revealed that there is a requirement for a low fuel level warning on all these aircraft categories.

For Normal, Utility, Aerobatic, and Commuter category aeroplanes the requirement is contained in EASA CS-23 Certification Specifications:

> *'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…'

1.18.9.3   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…'

1.18.9.4   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…'

1.18.9.5   FAA regulations

FAA regulations FAR 23, 27 and 29 are similar to the EASA regulations for the aeroplane and rotorcraft categories described above.

1.18.9.6   Previous FAA proposed rule.

In 1987 the FAA issued NPRM[13] 87-3 (see Appendix O). This proposed a change to FAR 25 to include a requirement for an independent fuel low-level warning.

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13   Notice of Proposed Rule Making.

In 2002 this NPRM was withdrawn (see Appendix P), due to the harmonisation of rules between Europe, Canada and the USA.

The following text is taken from the document entitled "FAA/JAA Harmonisation work program", 11th edition, June 1 2002:

"SPECIFIC TASKS:

This TOR covers several distinct tasks related to powerplant indications as follows:

1)assess the need for, feasibility of and provide recommendations regarding a new §25.1305(a)(9) regulatory requirement and advisory material for "a low fuel indication" displayed to the flight crew at any point during a flight where crew awareness is required to avoid fuel starvation for any main engine. This low fuel indication should be capable of annunciating inappropriate fuel loading or utilization, leaking or trapped fuel, or any other fuel system condition where flight crew awareness is expected to be required to avoid fuel starvation for one or more main engines, including when the fuel available for main engine fuel feed is below that required to safely complete the flight with adequate fuel reserves. No malfunction should affect both this indication and any fuel quantity indicator…

…REMARKS:

Task 1 is a continuation of the "low fuel warning" FAA rulemaking initiative originally proposed in NPRM 87-3 to mitigate the threat of fuel starvation. Fuel starvation has been one of the top ten causes of fatalities. As a result of this adverse service experience, public comments on the NPRM and further internal FAA coordination, the objective of this rulemaking has broadened and now is simply to highlight and prescribe how §25.1309(c) will be met for this particular unsafe fuel system operating condition. An acceptable means of compliance is foreseen as providing a continuous automated way point and fuel system monitoring capability which replaces or supplements the manual methods currently in use to avoid fuel starvation…"

The text of 25.1309(c) is shown in paragraph 1.18.9.2 above.

1.18.10   ARINC 429 protocol

ARINC specification 429 is a standard published by Aeronautical Radio Incorporated (ARINC) and developed by the Airlines Electronic Engineering Committee (AEEC). The standard was produced for digital data communication between avionic units. ARINC 429 utilises data buses which comprise two signal wires that transmit 32 bit words uni-directionally using the mark 33 Digital Information Transfer System (DITS) data bus standard. Each ARINC data word is 32 bits and consists of a parity bit, a sign/status matrix, the data, source/ destination identifier and a label. Normally the data is binary-coded decimal (BCD), twos complement binary notation (BNR) or discrete data. The digital signal is sent as a serial stream with a potential difference between the two signal wires indicating the digital 1, null or 0. The data transfer rate is either 100 K or 12.5 K bits per second.

1.18.11   FCMC development history up to Flight Load 8

The FCMCs fitted to G-VATL were at software flight load (Flight Load) 7. The standard is now at Flight Load 8.1 with ongoing development of the software. Before Flight Load 7 there were several earlier standards starting with Flight Load 4.1 which was the level used for the entry into service of the A340-600 aircraft and certified in July 2002.

The next software standard was Flight Load 5 which was certified in October 2002 and introduced improvements to several of the functions of the system.

In May 2003 Flight Loads 6 and 6.1 were certified, Flight Load 6 being an exclusive software load for the A340-500 with a basic wing and Flight Load 6.1 for all the remaining A340-500 and the A340-600 with modified wings and fuel tank layouts. This introduced many changes to the functional software and also started to introduce improvements to reduce the problem associated with spurious 'FCMC FAULT' messages as a result of the COM/MON disagree. The fix was attempted by the use of forced re-synchronisation of the two processes.

Flight Load 7 was certified in November 2003. Again several improvements and fixes to some in-service problems were implemented including improvements to the cockpit indications derived from the FCMC, the fuel transfer logic and the refuelling logic. Another attempt was made at solving the spurious 'FCMC FAULT' messages due to the COM/MON disagreement with improvements to the synchronisation; however subsequent testing showed this was ineffective. It was also known that FCMCs at Flight Load 7 had a software fault which resulted in spurious reporting of FDC FAULT warnings.

The next software update was Flight Load 7.1 which was certified in April 2004. Again this had several improvements to the system functions and fixes for existing problems. There were no further fixes implemented for the spurious 'FCMC FAULT' issue. However a change was made to the troubleshooting data in which the TSD wording was improved to assist in identifying the source of the failure which resulted in the TSD report.

Flight Load 8 software standard was certified in February 2005; it had already been developed and was about to be fitted to the operator's A340-600 fleet at the time of the incident. The major change within Flight Load 8 was a change to the monitoring of the fuel system to fix the problem with spurious FCMC FAULT messages.

1.19   Useful or effective investigation techniques

During this investigation it became quite obvious that the majority of the information that would assist in finding the root cause was within the various control computers. The recorded flight data was, as always, invaluable but this investigation required more information that was buried deep in the aircraft's computers. Fortunately, the A340-600 is one of the most advanced public transport aircraft in service and, as such, has a large amount of advanced avionics equipment. It was soon discovered that each of the computers contained fault memory, mainly used for troubleshooting and production of the PFR. This fault memory, contained on the FCMC, FWC, DMC, and the reports, such as the PFR, available from the CMC were all useful in understanding what had happened. However, as these are intended for in-service troubleshooting and not accident investigation, they had their limitations which will be discussed in the analysis. Nevertheless, accident investigators should be aware that buried deep in the computers of many Airbus aircraft, and probably other contemporary types, is a lot of data which should be extracted at the earliest opportunity. Because some computers only produce a hexadecimal readout, the original information may not look useful at first sight but when decoded by the manufacturer, it becomes very useful. Also, because each of the computers exchange data it is possible that a computer outwith with the suspected system may have clues as to what has happened within the faulty system. This distributed data was particularly evident during this investigation because the DMCs and FWCs contained information regarding the ARINC data bus status of the FCMCs.

Also, most operators of Airbus aircraft have a system which records each PFR following every flight. This can be more useful that the technical log,

especially if a history of faults needs to be collated. This could be true of a known repetitive fault which flight crews chose not to or are instructed not to report in the technical log. The review of previous PFRs provided useful information in this investigation because it gave an insight into the number of FCMC FAULT messages the flight crews were experiencing and also the length of time the INNER 4 TANK TEMP SENSOR fault had been prevalent on G-VATL. Both issues would have been difficult to correlate from the technical log alone.

2   Analysis

2.1   Introduction

Both No 1 and No 4 engines ran down because there was no fuel to supply them from their respective engine feed tanks, Nos 1 and 4 Inner tanks. There was plenty of fuel on the aircraft and there were no indications of a fuel leak.

The reason for the depleted fuel states in the inner fuel tanks was failure of the automatic fuel transfer system. Although manual override of the fuel transfer was available, it was not used until after the engines ran down because until then, the flight crew were unaware that the automatic fuel transfer system had failed.

Coupled with the lack of fuel system failure warnings, there was also a similar lack of warnings of the low fuel quantities in the Inner 1 and Inner 4 fuel tanks and their respective collector cells. The only indications to the flight crew of the failure of the fuel transfer system was the information presented on the fuel status page on the SD screen; information that is only displayed if the page is selected by the flight crew or if the system has detected and indicated a problem. The flight crew were not monitoring the fuel status page closely, nor were they required to. It was their expectation that if any fault were present there would be an amber indication, but they did not recall seeing any amber on the fuel system display page throughout the flight.

After the rundown of No 1 engine and following the opening of the fuel cross feed valves to recover No 4 engine, the flight crew were then puzzled by the symbols presented to them on the fuel status page. Indeed, when manual fuel transfer was underway, the flight crew were unsure whether the fuel was transferring into the inner fuel tanks, partly because the arrows that symbolise fuel transfer in progress were not displayed.

2.2   Operation of the aircraft

2.2.1   Flight crew qualifications, experience and training

The three pilots were properly qualified and experienced in their respective roles to operate this flight. At the time of the incident they had completed some 13 hours of duty, which was within their maximum allowable duty time.

2.2.2   Alertness and monitoring

It is generally accepted that human beings are not well adapted to a task of routine monitoring. This aspect of human performance makes the role of automated alerting and warning systems on aircraft particularly important on long sectors.

It is somewhat ironic, therefore, that in this long-range aircraft, of a modern design equipped with what were thought to have been fault monitoring systems with multiple redundancy, the first indication the crew had of any failure was the physical sensation of yaw caused by asymmetric thrust following the rundown of the No 1 engine.

At the time of the incident, the crew had been exposed to some 17 consecutive hours of darkness. Given this factor and that they were at the end of a long and routine flight, until the time of the No1 engine rundown, their arousal level was likely to have been fairly low.

2.2.3   Management of failures

FCMC problems on the aircraft had become so routine that they were effectively disregarded once the required circuit breaker pull and reset actions had been completed. In this case the flight crew were unable to reset FCMC2 at the top of climb and so they were reduced to a single FCMC but this did not cause them any additional concern.

There are three phases of the flight where it is worth considering further the actions of the crew.

Management of the engine failure

The first indications to the pilots of No 1 engine 'failure' at 0329 hrs was a yaw followed by the N_1 indication below 50%. These were followed by an ECAM alert of 'Engine No 1 Fail'. In his capacity as PNF, the co-pilot carried out the ECAM actions whilst the commander continued to operate as PF. The co-pilot selected maximum continuous thrust on the other three engines and responded to the ECAM actions. As these actions were carried out, the commander assessed that the loss of one engine should not affect the continuation of the flight and he also decided, with the destination being only one hour away, not to attempt to relight the engine.

While an ECAM Engine Fail procedure is being completed, it is expected that the PF will adopt the standard strategy for engine-out operations. However,

the ECAM procedure does not contain a prompt to consider if a lower cruise level may be required and it seems that a descent to the optimum flight level for three-engined cruise was overlooked. In fact this level would have been only marginally below FL380 so this omission was not significant.

One line of the ECAM procedure required the pilots to monitor fuel imbalance. The intent of this line is that following an engine shut down, a fuel imbalance will occur unless the pilots actively manage the fuel distribution so as to avoid any excessive imbalance. On this occasion, the pilots' initial reaction to the engine failure was that it could not be a fuel problem because there was so much fuel on board. Consequently, on reaching that line they commented that they would keep an eye on the fuel status but did not, at the time, bring up the fuel system synoptic page. This decision represented a missed opportunity to notice that there was zero fuel indicated in the Inner 1 tank feeding No 1 engine and less than 300 kg in the Inner 4 tank feeding No 4 engine. Detection and corrective action at this stage could have prevented the rundown of No 4 engine. Also, a diversion could have been avoided if the pilots had been confident that fuel was transferring out of the trim and centre tanks into the inner wing tanks.

About six minutes after the failure of No 1 engine, when the secondary ECAM actions had been completed, the pilots took time to consider the aircraft's status and the fuel system synoptic page on the ECAM system was manually selected. About that time the commander said "*WHY HAS THAT GONE TO ZERO*", most likely referring to the Inner 1 tank quantity. This fuel issue captured all the pilots' attention and the change of focus from engine failure to fuel management probably explains why the engine-out strategy was not fully adopted and why no descent was carried out.

Identifying the fuel problem

When the commander noticed that the Inner 1 fuel tank was empty he became concerned about the possibility of a fuel leak. After the A330 emergency landing at Lajes due to fuel exhaustion, there had been considerable focus on training flight crews to consider the possibility of a fuel leak. It is particularly important to consider leaks before opening the cross feed valves because if any lateral imbalance is caused by a leak, the onset of total fuel exhaustion can be hastened if the cross feed valves are opened. The commander was well aware of this potential issue and so he asked for the CFO to be woken up to go aft and check whether there might be a leak.

The pilots' concern about the possibility of a leak may have prevented them

from realising that the underlying cause of their engine failure was abnormal fuel distribution rather than fuel loss. Consequently, although the fuel system synoptic page was displayed for about a further three minutes, nobody referred to the fuel quantities in any of the other tanks. During those three minutes, the contents of the Inner 4 tank reduced from about 240 kg to about 88 kg when the page was deselected.

The commander then called the senior cabin crew member to the flight deck and briefed him on the situation. As he was doing so, the No 4 engine started to run down because of a lack of fuel in its feeder tank. The co-pilot very quickly noticed that the engine N_1 was reducing and advised the commander. The commander's action of opening all the fuel cross feeds and possibly the outer tank transfer valve was instinctive and contrary to the recommended procedures for a fuel leak, but his prompt action was effective in preventing the loss of the No 4 engine by quickly re-establishing its fuel supply.

Once again the focus of attention changed. The pilots were then very concerned about the situation of the aircraft. From this time onwards their priority became fuel management and preservation of supply. The three-engine status became a secondary focus. The commander decided that there were two courses of action they would take, firstly to attempt to relight the No1 engine and if that was not successful, to divert the flight to land as soon as possible.

Engine relight

The commander requested that an engine relight be attempted which was performed using the QRH procedure. The first line of the procedure states that the maximum guaranteed altitude for relight is 30,000 feet. Although read out aloud by the co-pilot, none of the three pilots seemed to have absorbed the information or said that a descent would be required, probably because most of their attention was focused on trying to understand the fuel problem. The relight procedure was continued and, because the aircraft was still at FL380, it was unsuccessful.

The commander then decided that a diversion was necessary and the aircraft started a descent towards Amsterdam. The CFO reported back that there was no sign of a fuel leak so all three pilots continued to attempt to resolve the reason for the fuel transfer problem.

2.2.4   Fuel management during the diversion

The FDR did not record the switch positions on the flight deck's overhead fuel systems panel but a combination of CVR and FDR data provided evidence of manual fuel transfer selection and effect.

The pilots initiated manual fuel transfer which resulted in fuel transferring forward from the trim tank to the centre tank and from the outer fuel tanks to the inner fuel tanks. Shortly after this the commander stated that the fuel was not transferring forward from the trim fuel tank to the centre fuel tank, although at the time the FDR indicated that the trim tank quantity was reducing at a rate of about 100 kg/minute. The pilots did not discuss fuel quantities being annotated, either before or after manual fuel transfer had been initiated, nor did they mention the absence of fuel transfer arrows which should have been present on the display during manual transfer. The relatively slow transfer rate and the lack of previous reference to the tank quantities before fuel transfer had been initiated would probably have meant that the reduction in tank quantity of about 200 kg may not have been immediately evident which led the pilots to believe that fuel was not transferring. The pilots then proceeded to set the trim tank feed switch on the overhead panel from the "OPEN" to the "AUTO" position, although this had no effect on the trim tank fuel transfer because it continued to transfer forward.

The commander then identified that fuel was not transferring from the centre tank and the pilots initiated fuel transfer from the centre to the inner fuel tanks. However, they then appeared uncertain as to whether the fuel in the centre tank was unusable. Shortly after the manual fuel transfer was initiated, fuel started to transfer from the centre tank to the inner fuel tanks.

Fuel continued to be transferred forward from the trim to the centre tank and from the centre to the inner fuel tanks until after the aircraft had landed.

2.2.5   ECAM procedures

If a technical fault is detected but no corresponding ECAM procedure is displayed, procedures may be available in both the QRH and the FCOM. Many of these procedures are 'hard' copies of the ECAM procedures which are specifically designed to be reviewed in conjunction with the ECAM. Also, it can be difficult for a crew to find a suitable procedure without a 'trigger' ECAM indication. The title pages have to be read carefully and a decision made as to the appropriate procedure, if any, to apply. Moreover, using the FCOM in this way to identify and solve system problems was never intended by the aircraft manufacturer.

2.2.6   The human factor consequences of fuel system complexity

Fuel transfer within the aircraft is both automated and complex as fuel is used to manage the aircraft's centre of gravity in flight. Because of the automation and complexity of fuel management, pilots are unlikely to acquire a confident expectation of what is a 'normal' fuel distribution during flight. The presentation of fuel quantities is in digital format and it needs particular attention to summate and cross-check fuel distributions. For example, to determine the total fuel quantity in one wing, perhaps to evaluate any lateral fuel imbalance, the contents of three tanks have to be added. These factors make it less likely that pilots will notice an 'abnormal' distribution without assistance from automatic fault detection.

Once the pilots appreciated that the fuel transfer system had malfunctioned without any warning, they partially lost confidence in the ECAM upper and lower displays. However, had they been displayed, transfer arrows on the fuel system synoptic page and/or fuel transfer memos on the upper ECAM display could have restored confidence in their ability to transfer fuel manually. Unfortunately, these symbols were suppressed and so the pilots were uncertain about the efficacy of manual transfer.

2.3   Air traffic control

Air traffic control communications with the aircraft were good and the crew were given all the assistance they required. The use of a dedicated frequency ensured that there were no distractions or interruptions in communications for the final stages of the flight.

2.4   FDR analysis

The FDR recorded the fault status of both FCMC1 and FCMC2. During the incident flight there was one recording of a fault status, which was from FCMC1 and it occurred as the aircraft taxied for takeoff. Both FCMC fault parameters were recorded at a rate of once every four seconds; at that recording rate it was possible that a FCMC fault that lasted up to three seconds in duration would not have been recorded.

The fuel transfer appeared normal during the takeoff and climb phases of the flight. As the aircraft climbed through FL250 the trim tank quantity started to increase. The trim tank quantity continued to increase until it finally stabilised at about 6,280 kg, where it remained until manual fuel transfer was later initiated.

At about three hours after takeoff the centre fuel tank stopped transferring fuel to the inner fuel tanks. The centre tank quantity was about 5,312 kg when transfer stopped.

From about 1928 hrs, when the centre fuel tank stopped transferring, to the time just before the Inner 1 fuel tank quantity had reduced to zero, at about 0340 hrs, the pilots had selected the fuel synoptic page on the lower ECAM display on six separate occasions. The durations of display varied from between about 12 seconds to less than 4 seconds. The most recent display of the fuel page before depletion of the Inner 1 fuel tank occurred about 38 minutes before the rundown of the No 1 engine. On that occasion the fuel page was displayed for less than four seconds.

From the time when the No 1 engine had rundown to the time when the aircraft started its descent following the MAYDAY the airspeed had decayed by 16 kt with the rate of decay being about 1 kt every 90 seconds. The gradual reduction in airspeed had resulted from the reduced aircraft performance following the loss of the No 1 engine. At the time of the MAYDAY and subsequent descent the crew had not identified that the airspeed was slowly reducing.

2.5   Technical analysis

This analysis examines the technical factors which probably caused the initial failure of the automatic fuel transfer system. The analysis includes the role of the FCMCs, the subsequent lack of warnings, the fuel status display, issues with manual fuel transfer, the reason for the inability to restart No 1 engine and issues surrounding both the availability and the usefulness of the data downloaded from the various computers fitted to the G-VATL.

2.5.1   Automatic fuel transfer failure

According to the flight data recording and the FCMC TSD, the automatic fuel transfer was operating correctly until 1934 hrs but afterwards, no further automatic transfers took place. In normal operation the fuel quantities in the Inner 1 and Inner 4 tanks are kept at between 17,200 kg and 18,200 kg until the centre tank is empty. Similarly, the Inner 2 and Inner 3 tanks are kept between 24,700 kg and 25,700 kg. During this phase the centre tank fuel is transferred via transfer valves automatically commanded by the master FCMC in control at the time.

Therefore, according to the flight data, at 1941 hrs, when the Inner 1 fuel contents dropped below 17,200 kg, the Inner 1 fuel tank transfer valve should

have been commanded open by the master FCMC and fuel should then have transferred from the centre to the Inner 1 fuel tank. Similarly, at 1956 hrs, Inner 4 fuel tank contents dropped below 17,200 kg and fuel transfer should have then taken place. In both cases this did not occur and the centre fuel tank contents remained at 5,312 kg until the manual fuel transfer actions taken by the flight crew after engines No 1 and No 4 ran down. Similarly the fuel in the outer tanks and the trim tank remained at the same fuel level after 1934 hrs. Therefore the fuel remaining in the Inner 1,2,3 and 4 at 1934 hrs became the only usable fuel for each engine respectively until the cross feed valves were opened and the manual fuel transfers were finally underway.

Until 1941 hrs the automatic fuel transfers were conducted by the master FCMC. If the slave FCMC detected that the master FCMC had failed, it should have assumed control and become the master FCMC. Therefore from 1941 hrs onwards, both the master and the slave FCMCs must have lost their ability to command the fuel valves and pumps.

Each fuel valve and pump was commanded by an analogue discrete signal generated internally within both the master FCMC and the slave FCMC via their DOUT cards. The only difference was that the slave FCMC had its DOUT card inhibited by its COM processor. The command for the signals to be sent out to the valves via the DOUT was calculated by the COM processor based on the fuel quantity inputs from the FDCs. Similarly the MON processor within the FCMC monitored the internal calculations by the COM and worked out whether the COM was in fact commanding the correct valves. If the MON detected a discrepancy with the COM, it would have inhibited the DOUT and failed the FCMC, handing control from the master FCMC to the slave FCMC. Feedback from the commanded fuel valve or pump about its status would have been received by the FCMCs via their DIN cards. Again, if a discrepancy was found between the commanded DOUT and the feedback of the valve or pump position on the DIN, then the respective pump or valve would have been failed by the FCMC and a warning sent to the FWC.

A failure to command the automatic fuel system could have occurred due to a failure of the individual fuel valves and pumps commanded by the FCMC. To have all the fuel valves and pumps fail at the same time is extremely improbable so this explanation was thought to be unlikely. Also, in the later stages of the flight, the fuel valves and pumps that would have had to fail to render the automatic fuel transfer inoperative were later controlled manually.

A possible explanation was failure of the discrete outputs from the master

FCMC in command at that time. The inhibition of the discrete output can occur due to the FCMC detecting an internal problem, such as a mismatch between the calculated outputs from the COM and MON processors, or due to a failure of the COM processor itself. There was a known problem with the COM and MON processors within the FCMC resulting in a 'FCMC1(2) FAULT' messages which will be discussed later.

The TSD from FCMC2 indicates that at 1941 hrs it had calculated that the Inner 1 transfer valve should have been opened as the fuel quantity in that tank dropped below 17,200 kg. However, because the valve had not opened, the FCMC detected and reported internally that the valve had failed shut. Similarly, at 1934 hrs the TSD for FCMC1 and FCMC2 show detected failures to operate of the centre fuel tank left and right transfer pumps and the refuel auxiliary valves. This list of TSD failures indicated that both FCMCs were correctly calculating which valve should have been moved and when. Yet the feedback received was not as expected, resulting in the commanded fuel valve or pump being reported as failed. This information from the TSD points towards a failure of the discrete outputs from the master FCMC.

Unfortunately, later testing failed to find a reason for the failure of the discrete outputs, as both FCMC1 and FCMC2 passed all their bench tests. It was known that FCMC2 had suffered a failure of some kind early in the flight, at 1621 hrs, and that it was still indicating as failed under 'STATUS' following the No 1 engine rundown. It is possible that FCMC2 had suffered an internal failure, such as a COM/MON disagree resulting in the shut off of its DOUT board. Also, at 1934 hrs there was an FCMC1 maintenance status message recorded on the PFR. Unfortunately, it was not possible to definitively establish, from the PFR or TSD, why FCMC 1 and FCMC 2 had detected failures. The fact remains that neither FCMC1 nor FCMC2, regardless of which was master, had control of the fuel system valves and pumps after 1934 hrs.

2.5.2   Fuel warnings

During the incident flight it was apparent that the flight crew were not aware that the automatic fuel transfer system had failed, mainly due to the lack of any ECAM warnings. The first warning that should have occurred was 'CTR/INR TK XFR FAULT' at 1941 hrs, due to the Inner 1 fuel tank quantity dropping below 17.200 kg with fuel remaining in the centre tank. This warning would have then been shown again at 2114 hrs when the Inner 1 fuel tank quantity dropped below 14,000 kg. The ECAM action would have then directed the flight crew to use the manual fuel transfer to move fuel from the centre to inner fuel tanks.

At 0128 hrs the fuel quantity in Inner 1 dropped below 4,000 kg, which should have triggered a forward transfer of the trim tank fuel. As this did not occur the 'T TK XFR FAULT' warning should then have been indicated. The ECAM action for this fault would have required a manual transfer of the trim tank fuel.

At 0228 hrs the fuel quantity in the Inner 1 tank reached 2,000 kg, the quantity at which fuel transfer from the outer to the inner fuel tanks should have begun. Because the transfer did not take place, there should have been an ECAM warning of 'OUTR TK XFR FAULT'. The ECAM action for this fault would have required operation of the manual outer tank transfer switch.

At 0258 hrs the Inner 1 fuel quantity reduced to 1,000 kg, the trigger level for the 'INR 1 LO LVL' warning. The ECAM action for this warning would have been to open the cross feed valves and to operate all the manual fuel transfer switches on the overhead panel. If the 'INR 1 LO LVL' warning had not been triggered then the next warning should have occurred when the Inner 1 collector cell quantity dropped below 750 litres, triggering the 'CELL 1 NOT FULL' warning requiring the cross feed valves to be manually opened.

All of the above warnings should have been commanded by the master FCMC and sent to the FWCs via the FCMC ARINC output buses A and B. Clearly, there are three potential explanations:

  a. Both FWCs were inoperative.

  b. The warnings were not generated by the master FCMC.

  c. The ARINC output buses between the master FCMC and the FWC were inoperative.

At 0330 hrs, following the rundown of No 1 engine, at least one FWC correctly warned of the engine rundown and the subsequent failures of the affected secondary systems. Also, full tests of the FWCs following the incident did not reveal any defects and the DMCs to which each FWC communicated did not show any FWC failures in their TSD. Therefore, double FWC failure may be discounted.

A failure of the FCMC to correctly compute the failures was possible and indeed software standard Flight Load 7 had been shown to have problems within the ICP. However, later tests of both FCMCs showed that they correctly computed the required failures and communicated these on the relevant ARINC output buses. In addition, the TSD for FCMC2 had shown a detected failure of its ARINC output

bus A, which would tend to indicate a failure with the FCMC ARINC output buses rather than the ability of the FCMC to compute the need for warnings. Consequently, the master FCMC was probably still generating warnings.

A failure of FCMC2 ARINC BUS A on its own would not cause a loss of the FWC generated warnings. Firstly, if FCMC2 was the master FCMC, it would still have a serviceable output ARINC BUS B connected to FWC2. The logic between the FWCs is such that if one FWC has been commanded to produce a warning then it takes priority over the other FWC, so if ARINC BUS B was still active then FWC2 would have generated the required warnings.

Thus, for a lack of warnings the most probable explanation is a failure of the ARINC output buses A and B from the master FCMC. These are the buses that communicate with the FWCs. The problem with this explanation is that there is more than one FCMC, and if both ARINC output buses A and B on one FCMC fail, the other FCMC should take over as master. This failure mode suggests that both FCMCs had lost their ability to produce warning signals.

The potential inability of the slave FCMC, due to its health status, to take over control from the master FCMC is discussed later in paragraph 2.5.4.

2.5.2.1   Low fuel quantity warnings

Failure of the master FCMC's output buses explains the lack of fuel transfer and the collector cell low quantity warnings since these can only be generated by the master FCMC.

The low fuel warning should have been generated within the master FCMC based on the weight of the fuel using the information from the fuel probes, fuel temperature sensors and the fuel densitometer, via the FDCs. Internally within the master FCMC, the COM should have calculated the fuel quantity. When it fell below the 1,000 kg threshold, the FCMC output should have triggered the 'INR 1(2,3,4) LO LVL' warning in the FWC. In addition, the ICP within the master FCMC should also have calculated the same fuel quantity, but using a dissimilar algorithm, and it too should have triggered the 'INR 1(2,3,4) LO LVL' warning. The ICP would have monitored the output of the master FCMC and having detected that a low level warning should have been generated, and yet not been sent on the ARINC output line, it should have shut down the master FCMC. This action should have caused an immediate switchover of master control to the other FCMC. Instead, errors in the Flight Load 7 software within the FCMCs prevented the ICP from shutting off the master FCMC and no exchange of master status took place.

However, the FWC was able to trigger the 'INR 1 LO LVL' warning from another source: the FDC. The FDC low-level discrete parameter would have been set when the fuel level in the tank dropped to a specific volumetric level. This meant that it would trigger at various fuel masses due to changes in fuel density and temperature. For Inner 1 the FDC would have triggered the fuel low level discrete at a fuel mass of between 704 kg and 840 kg. Therefore, the low fuel level discrete from the FDC would have been received by the FWCs after the low level ARINC 429 signal from the master FCMC.

Should both FCMCs fail, this FDC discrete was to be the back-up fuel low level warning. However, the FWC logic is programmed to disregard the signal from the FDC unless both FCMCs have failed, which can either be due to the FCMCs themselves signalling to the FWC that they have failed or due to a detected cut-off of the ARINC output bus signals from both FCMCs. If the FWCs had detected a total ARINC bus failure from both FCMCs, then they would have independently generated a 'FCMC1+2 FAULT' warning on the ECAM display. This did not occur on the incident flight so at least one FCMC was detected as being operational by the FWCs. Consequently, the FWCs would have disregarded the FDC low level warning signals.

In this case, if the system logic had been designed so that the back-up FDC discrete signal could override or supplement the FCMC ARINC 429 low fuel level signal, then the 'INR 1 LO LVL' warning would have been indicated to the flight crew and the appropriate manual fuel transfers undertaken. The reasonable expectation would be for the back-up system to have a capability to trigger a warning and to be independent of the status of other systems. Therefore, in March 2005 the following Safety Recommendation was made:

> 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. (Safety Recommendation 2005-37)

2.5.3   Fuel status page displays

One aspect of the investigation focused on what was presented to the flight crew before and during the incident. The main source of fuel status information available to the flight crew on G-VATL was the fuel page on the lower ECAM display. The fuel page would only have been displayed when selected manually by the flight crew or if the FWC had commanded the screen to appear when

it detected a fault. It is already known that from 1934 hrs, the FWC did not produce any fuel-related warnings and so it would not have automatically called the fuel page.

Therefore, the flight crew would have had to have selected the fuel status page to review the system operation during the incident. The FDR data shows that they did so six times but during these 'reviews' the flight crew did not detect a failure of the automatic transfer.

The only method of detecting the transfer failure would have been to record the fuel quantity in each tank during each review and compare this review with the previous to detect that correct fuel transfer, particularly from the centre tank to the wing tanks, had occurred.

However, the scope of the automation in contemporary Airbus aircraft subtly encourages reliance on the fuel computers and flight warning system to manage and monitor fuel transfer. The information on the CRUISE status page shows the fuel burn by each engine and the total fuel used. This information, coupled with the total fuel on board shown on the upper ECAM display, does not take into account where the fuel is or how much fuel is available to each engine at any one time. Moreover, since no fuel had been lost, comparison of these totals with the fuel loaded and the fuel required to reach destination would not have shown anything amiss. Expressing this issue simply, there was adequate fuel on board but it was not in the right places and the flight crew were not checking its distribution, nor were they required to do so.

It is evident that the flight crew were unaware of the failure of the automatic fuel transfer system and that the inner fuel tanks were slowly being starved of fuel. Failure of the master FCMC ARINC output buses A and B led to the lack of warnings. Similarly, a failure of the same buses would also have prevented the indication of problems on the fuel status page and lights on the overhead panel. A failure of ARINC output buses A and B from both the master and slave FCMC would have resulted in a loss of the fuel quantity with amber XX symbols replacing the fuel quantity figures and a loss of fuel quantity on the FDR. However, during the discussion by the flight crew following the engine run down, they questioned each other on why the Inner 1 fuel tank quantity was zero, which suggests that digits and not XX symbols were displayed. In addition, the FDR clearly shows fuel quantity throughout the incident. The DMC had the ability to select the source of the fuel quantity data from either the master or slave FCMC. Therefore, even with a failure of the ARINC outputs on the master FCMC, the fuel quantity data was still being provided by the slave FCMC.

The master FCMC would normally have provided the commands to the DMC to display the position of valves, pumps and fuel transfer arrows. Included in this list is the display of the fuel quantity in amber if it drops below the low level threshold and the display of the collector cell quantity if that drops below 1,000 kg. However, with the scenario of a failure of the ARINC output from the master FCMC, the DMC is not able to display these items correctly; instead it uses default indications such as green fuel quantity numbers.

Fortunately the DMC obtains status information for the LP valves, cross feed valves, engine fuel pumps and engine standby fuel pumps from the SDAC. Consequently, when the Inner 1 tank was exhausted, the only amber indications that would have been shown on the fuel status page were the LO pressure indications on the engine and standby engine fuel pumps. Similarly, the amber 'FAULT' lights in the fuel pump switches on the overhead panel would also have been illuminated.

It is already known that at 1934 hrs FCMC2 suffered a failure of its ARINC output bus A. This same ARINC bus supplies DMC 3 which in turn supplies the ECAM EW/D and SD. Therefore, if FCMC2 was the master FCMC, then the symptoms described above would be experienced. This tends to indicate that FCMC2 was probably the master FCMC at the time of the incident; if so, FCMC1 would have been the slave.

2.5.4   FCMC master/slave relationship

From the analysis so far it is thought that the ARINC output buses and the discrete outputs from the master FCMC had failed to operate correctly from 1934 hrs. The following analysis will expand on the role of the FCMC and also the effect the master/slave relationship between the two FCMCs had on the subsequent system response.

The analysis has discussed the possible reasons for the failure of the automatic fuel transfers and the fuel warnings. Both failures indicate loss of the control signals from the master FCMC but the slave FCMC should have taken over control and become master.

The determination of which FCMC is master at any one time is by the use of health levels. Each FCMC determines its own health level through continuous monitoring of its status. The healthiest FCMC becomes the master, with the remaining FCMC taking up the slave position. Should a failure occur within the master FCMC, it should degrade its health level and the slave then takes

on the master's role. However, if a situation arose in which the slave FCMC already had a degraded health state due to a previous problem then it may not be able to assume the master role, thus leaving the degraded master FCMC still in control.

During the previous sector FCMC1 and FCMC2 each suffered a failure which eventually resulted in the 'FCMC1+2 FAULT'. The flight crew's action was to carry out a reset of FCMC1 because it was thought to be another failure relating to the COM/MON disagreements. On the ground at Hong Kong the FCMCs both tested satisfactorily. However, whilst taxiing for departure, the 'FCMC1(2) FAULT' flickered on, although at the time it was not known to which FCMC this related. However, the FDR shows that at 1615:29 hrs, an 'FCMC1 FAULT' was triggered; this fault would not have been relayed to the flight crew because it would have been inhibited during this phase of the flight. If the fault still persisted once the aircraft reached cruising level, the FWCs should have indicated the fault to the flight crew via the ECAM EW/D. This triggering of the 'FCMC1 FAULT' shows that there was a problem with FCMC1, and so FCMC2 should have taken control as master. At 1621 hrs there was a fault with FCMC2, which resulted in an 'FCMC2 FAULT' caution message displayed on the EW/D. At 1655 hrs the flight crew carried out a reset of FCMC2 by using the reset CB. Despite this reset it is known that FCMC2 remained in a failed state. After the engine rundowns, FCMC2 was still listed as failed under 'STATUS' on the SD page, and was mentioned by the flight crew during their post engine failure checks.

At 1934 hrs FCMC1 suffered a failure, or detected a failure of FCMC 2, which resulted in a class 2 status message being generated. Although, it is not known what caused the failure, together with previous problems, it may have resulted in FCMC1 having a lower health status than FCMC2. It was also at this point that FCMC2 suffered a failure of its discrete outputs and ARINC BUS A.

It would appear that FCMC1 had not suffered an output failure and was still able to compute and detect failures of the various valves and pumps to operate after 1934 hrs. This was mainly determined from the lack of any TSD showing an output failure on FCMC1 and from the fact that that fuel quantity was still being displayed on the fuel SD page. There is clear evidence that the master FCMC had lost its ability to control the pumps and valves via its discrete outputs. The fact that FCMC1 detected a discrete output failure on FCMC2 indicates that FCMC2 was master. In addition, FCMC2 lost ARINC output bus A which would have resulted in the lack of information being displayed to the flight crew on the SD fuel page, again adding credence to the deduction that FCMC2

was master. It was also determined that FCMC2 ARINC BUS B must also have failed, otherwise the FWC would still have received the data necessary to display the fuel warnings.

When FCMC2 suffered the discrete output failure and the failure of its ARINC BUS A, it should have relinquished its master status and handed control to FCMC1. Clearly this did not happen; if it had then numerous fuel warnings would have been generated and the automatic fuel transfer may have continued to operate.

FCMC1 must have suffered an internal failure, resulting in a lower health level than FCMC2, because it failed to take control as master. Unfortunately, there is not enough information available to determine the health status of either FCMC1 or FCMC2 at the time of the incident, nor was it possible to determine what might have caused the degradation of FCMC1 health.

This set of circumstances leads to the probability that the master FCMC can remain as master despite losing all of its discrete and ARINC controlling outputs. This can occur despite having a slave FCMC capable of commanding the FWC to display the 'FCMC1+2 FAULT' or other fuel warning messages. Therefore the following Safety Recommendation was made in March 2005.

> 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. (Safety Recommendation 2005-36)

2.5.5   Manual fuel transfers

Following the opening of the fuel cross feed valves, after No 4 engine had started to run down, the pilots realised that fuel was in the wrong tanks and so they started to carry out the procedures for a manual transfer. However, during this process they were uncertain whether fuel transfer was actually taking place. The FDR shows that at 0349 hrs the fuel in the trim, left and right outer tanks started to decrease coincident with fuel quantities in the inner and the centre tanks increasing. This indicated that the pilots had managed to initiate the manual fuel transfer. They commenced manual fuel transfer at 0347 hrs. However, three minutes later, they discussed the status of the fuel system and their collective perception that fuel was not transferring from either the trim or centre fuel tanks. At that point they considered other procedures in an attempt to transfer the fuel. In normal operation the fuel SD page shows fuel transfers in progress by the

use of transfer arrows which point in the direction that the fuel is moving. This is true for both the AUTO operation controlled by the master FCMC and a manual fuel transfer controlled by the switch selections on the overhead panel. The transfer arrows on the fuel SD display are produced by the DMC based on information solely from the master FCMC. In the event that both FCMCs have failed then the DMC no longer receives any information for the display of the transfer arrows. This is also true for the scenario of the master FCMC failing to produce any outputs on its ARINC lines, but the slave FCMC still has some fuel quantity data on its ARINC lines. This would lead to the correct display of the fuel quantities but not information about fuel transfers in progress. The confusion experienced by the flight crew further adds to the theory that the master FCMC was no longer providing any outputs on its ARINC lines.

The only way the flight crew could be sure that manual fuel transfer was in progress would be to monitor the slowly changing fuel quantities in each of the fuel tanks. This would have been difficult during the period of high workload whilst they were preparing for a diversion. The CVR indicates that eventually the flight crew appreciated that fuel was moving some six minutes after the fuel started to move.

The fact that following an FCMC failure, fuel transfer arrows may not be displayed during a manual fuel transfer is not published in any documentation. Indeed, even the procedure following a 'FCMC1+2 FAULT', although calling for manual transfer, makes no mention that the fuel transfer arrows will not be indicated.

2.5.6   PFR/TSD/CMC relationship

The availability of the post flight report and the troubleshooting data proved invaluable, especially when it was combined with the data from the FDR and CVR. However, there were some limitations to this data which, if these limitations had not existed could have assisted in identifying or at least further verifying the analysis based on the available information.

The PFR is a report produced by the CMC following every flight and is used by operators to identify areas on the aircraft that require further troubleshooting. This PFR is a valuable tool and is especially useful in looking at trends such as the 'FCMC1(2) FAULT' frequency. However, it does have limitations which restrict the full potential of this valuable aid. Firstly the PFR only shows the first occurrence of the event. This means that if there is an intermittent fault

or indeed two separate occurrences of the same fault message for differing reasons, these are hidden from view. In addition, the correlation that is carried out by the CMC at the time that the first fault is recorded is designed to collate all the same ATA chapter related faults together and show only the first fault actually detected. This can hide the actual fault that caused the cockpit effect that was presented to the flight crew at the time; listed under 'COCKPIT EFFECTS'.

The PFR from the incident flight on G-VATL is a good example of the hiding of multiple fault occurrences and the hiding of the fault that causes the cockpit effect. The first example is the 'FCMC2 FAULT'; the PFR shows that this message occurred at 1621 hrs and was related to a hard fault with the 'INR TK 4 TEMP SNSR'. Because the 'FCMC2 FAULT' message already appeared on the PFR, any further faults resulting in the FWC signalling a 'FCMC2 FAULT' would be ignored. This means it is not possible to establish how many occurrences of 'FCMC2 FAULT' there were during the flight. The second point is that the 'INR TK 4 TEMP SNSR' on its own should not have resulted in the 'FCMC2 FAULT' message. This indicates that during the correlation window opened when the CMC received the 'INR TK 4 TEMP SNSR' fault from FCMC2, the FWC also sent the 'FCMC2 FAULT' to the CMC and there were additional ATA 28 faults received from both FCMC1 and FCMC2 during that period, including the genuine reason for the fault indication. Therefore, it was not possible to find out exactly what caused the 'FCMC2 FAULT' indication at 1621 hrs.

Another example is the FCMC1 maintenance status message at 1934 hrs. The first fault received was the 'FUEL TRIM TK ISOL VALVE' from FCMC1. However, during the correlation window the cockpit effect received by the CMC via the FWC was for an FCMC1 maintenance status message. The 'FUEL TRIM TK ISOL VALVE' message is a class 1 fault and the maintenance status should only occur with a class 2 fault, so for this reason the PFR produced by the CMC does not show a cause of the maintenance status message. An asterisk by the source 'FCMC1' on the next box down, listed under 'FAULTS' for the 'FUEL TRIM TK ISOL VALVE' indicates that at least one of the faults received during the correlation window was a class 2 fault. Because the class 2 fault was hidden behind the class 1 trim tank isolation valve fault, it was not possible to establish why the maintenance status message FCMC1 was produced by the FWC.

The information on the PFR is normally augmented by further interrogations of the troubleshooting data of the affected components. However, limitations in the TSD provided by some computers were also discovered. Firstly, the

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TSD on the FCMCs should have stored the faults detected during the incident flight. In normal circumstances, interrogation of this data would correlate with the faults received by the CMC and those reported on the PFR. Therefore, it should be possible to establish what actually caused the fault message on the PFR to be generated, even when more than one fault occurred during a CMC correlation window. However, the TSD was limited to recording only eight faults in any one flight. This was because it was thought unlikely that more than eight faults would occur in one flight. On the incident flight however there were significantly more than eight faults on both FCMC1 and FCMC2. Moreover, on receipt of the 9th fault the 1st fault was overwritten, resulting in only the last eight faults being recorded. Therefore the TSD for the FCMCs only contained the last eight faults which were mostly related to detection of pump and valve operational failures after the failure of the automatic fuel transfers. Fortunately, some of the original faults at 1934 hrs had not been overwritten enabling some analysis of the root cause. However, had the TSD recorded just the first eight faults then it may have captured the reason for initial failure of FCMC2 and the reason for the FCMC1 maintenance status message. This information could then have led to the determination as to which FCMC was actually in control at the time and a more accurate determination of the root cause. Software standard Flight Load 8, introduced shortly after the incident to G-VATL, contained a change in the code so that the FCMC TSD will, in future, store the first eight faults in any one flight.

Fortunately, the FCMC TSD is provided in plain English, albeit with some hexadecimal coding. As a result, when the TSD is retrieved on the aircraft, maintenance staff can use the data immediately to assist in troubleshooting the system. On the other hand, the FWC and DMC TSD are only provided in hexadecimal code when interrogated on the aircraft, making the TSD difficult to read and interpret. A full decode requires the assistance of the aircraft manufacturer. This takes time and reduces the usefulness of this data. Indeed, faced with a screen full of hexadecimal codes, a maintenance engineer is unlikely to download the data for decoding, opting to ignore it even though it may assist in the diagnosis of a fault.

In summary, the limitations of the PFR and the FCMC TSD meant that it was not possible to establish the full sequence of events. Due to the repetitive fault with the Inner 4 tank temperature sensor, the PFR indicated an 'FCMC2 FAULT' related to this fault at 1621 hrs, thus hiding the real reason for the 'FCMC2 FAULT' and masking any subsequent occurrences of the fault message. Similarly, because the earlier faults in the FCMC1 and FCMC2 TSD were overwritten by later faults, neither the precise causes of the failures nor the entire sequence of events

could be determined. Nevertheless, the additional information provided by the PFR and the TSD allowed the investigation to establish the majority of the facts in which to make judgements on follow up safety action to prevent recurrence.

2.5.7   FCMC COM/MON failures

During the investigation it became clear that the FCMC did not have a good reputation for reliability amongst operators of the A340-600. This was borne out by a review of the frequency in which FCMC1(2) FAULTS had occurred on the aircraft type. A flight crew would typically have expected to see the FCMC1(2) FAULT on half of their sectors. The problem was due to the clocks between the COM and MON becoming asynchronous. Normally a reset of the FCMC by tripping and resetting the CB would reset the clock and restore normal operation. In some cases if the CB was not tripped for long enough for the FCMC to reset, it remained in a failed state.

Because the COM/MON disagreement was a common fault experienced in flight, it was largely ignored by maintenance crews. Indeed, most flight crew did not record in the technical log that the FCMC fault had actually occurred in flight. The normal action by the ground crew was to reset the computer and carry out a BITE check on the ground; if this cleared then it was declared serviceable. It was unusual for any further troubleshooting to be carried out on the FCMC. Indeed, Airbus instructed that there was no need for further troubleshooting after a successful reset.

During the incident on G-VATL there were several occurrences of 'FCMC1(2) FAULT' messages prior to the flight. Indeed, whilst at the gate both FCMC1 and FCMC2 failed and required a reset by the flight crew. Also, during the previous flight the 'FCMC1+2 FAULT' message appeared and FCMC1 was reset in flight. On the ground a reset and BITE test proved satisfactory. It was not possible to establish the reason for these FCMC faults although the problem with the Inner 4 tank temperature sensor and its effect on FDC 2 seem to be a likely source. However, it is likely that a combination of the Inner 4 tank temperature sensor fault and the COM/MON disagreement faults within the FCMC caused the FCMC faults. Although these faults had occurred and were reported via the FWC, they would not, in isolation, have resulted in a failure of the automatic fuel transfer system or the lack of fuel system warnings as experienced on G-VATL. If the COM/MON disagreement and temp sensor faults had led to the failure experienced on the aircraft, then it would have occurred with a high frequency on other A340-600 aircraft, mainly by virtue of the rate of COM/MON disagreements with the software standard Flight Load 7.

Since the operator has introduced the latest software standard Flight Load 8, the frequency of 'FCMC1 (2) FAULTS' has dropped significantly with the fault message now a rarity rather than a regular occurrence.

2.5.8   FDC and Inner 4 tank temp sensor

The PFR indicates that FDC2 failed at 1626 hrs. This produced the 'FDC2 FAULT' message. The crew action for this message would have been to monitor the fault. Later in the flight, when the crew were discussing the system status they did not mention FDC2, meaning that the fault probably rectified itself at some point in the flight. This indicates that there may have been a intermittent fault within FDC 2 that may have been related to TSP B within the FDC, as evidenced by a fault recorded on the TSD on 3 February 2005. Although it is also possible that the known software issues with FCMC Flight Load 7 had caused a spurious FDC warning.

Due to the limitations of the FCMC TSD and the fact that the FDC has no internal memory, it was not possible to establish the cause of the possible intermittent fault with FDC2. Later tests on both FDCs were satisfactory and the Inner 4 tank temperature sensor fault was found to be due to a loose connector.

FDC2 provides the fuel data to both FCMCs, along with FDC1. A failure of FDC2 would not render the fuel control system inoperative, nor would it have affected the FCMC control of the automatic fuel transfer or fuel warning systems. Therefore, an intermittent failure of FDC2 and the faults with the Inner 4 tank temperature sensor were not thought to be a factors in this incident.

2.5.9   Engine relight failure

Following the rundown of No 1 engine and after the opening of the crossfeed valves to supply fuel to No 4 engine, the flight crew attempted to relight engine No 1 engine. During the start procedure the engine N3 (HP spool) speed reached about 19% but the compressor stagnated. Consequently the attempted relight was terminated and the engine shut down.

The reason the engine failed to relight was because of the aircraft's high altitude. At FL380 the air density was low and there was relatively low ram air pressure into the engine so it is unlikely that combustion would have taken place. If it had, it is unlikely that the engine would have accelerated. Compressor stagnation with a subsequent increase in Total Gas Temperature (TGT) was likely if combustion occurred. The control system would have detected this increasing TGT and would have terminated the engine start sequence as a precaution.

2.6   **Regulatory requirements**

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 if the crew are not aware of the situation when the system fails to operate correctly, engine fuel starvation can occur without warning.

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 sub-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 critical warnings such as low fuel levels in the engine feeder tanks.

Another argument for not having an independent low fuel level warning could be that aircraft certified to EASA CS-25 are operated by a minimum of two flight crew and therefore at least one pilot would be monitoring the fuel status. However, with larger aircraft, the fuel system may be used for centre of gravity control so fuel tank feeding sequences may be complicated. Also, 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.

Although fuel distribution can be managed by computers, the flight crew also have to monitor several other complex aircraft systems and do so for long periods. The human factors issues have been addressed by automated warning systems but this incident demonstrates that total reliance on software driven warning systems is misplaced.

From the above regulations it is clear that there is currently no requirement within EASA CS-25 or JAR-25 for an independent 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 provision as defined by the relevant EASA Certification Specifications CS-23, CS-27 and CS-29.

As this incident demonstrated, 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 diverting.

There are two main certification agencies for very large aircraft: the European Aviation Safety Agency and the US Federal Aviation Administration. Consequently, each of two Safety Recommendations was addressed to both bodies.

> 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 2005-108)

> 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 2005-109)

> 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 2005-110)

> 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). (Safety Recommendation 2005-111)

3 Conclusions

(a) Findings

1. The flight crew were properly licensed, adequately rested and medically fit to conduct the flight.

2. The flight crew operated the aircraft within the limits laid down by the operator's Flight Time Limitations scheme.

3. The crew carried out all normal operating procedures in accordance with their company Operations Manual, both before and during the flight.

4. The flight crew were aware of the FCMC resets which had occurred on the previous flight sector from Sydney.

5. Before departing Hong Kong Airport the flight crew performed a successful computer reset for both FCMC1 and FCMC2.

6. The first perception of a problem, by the flight crew, was when No 1 engine lost power at 0328 hrs.

7. No 1 engine ran down due to fuel starvation when its feed tank ran dry.

8. No 4 engine started to run down due to fuel starvation as its feed tank emptied.

9. At the time of the engine rundowns there was sufficient fuel on board the aircraft for the remainder of the flight to Heathrow.

10. There was no fuel leak.

11. The arousal levels of the flight crew at the time of the engine rundown were likely to have been low.

12. Following the run down of No 1 engine, the flight crew did not review the aircraft fuel status in sufficient detail to notice the impending fuel starvation of No 4 engine.

13. The flight crew attempted a relight of No 1 engine at FL380, whereas the QRH states that the maximum guaranteed altitude for a relight is FL300.

14. No 1 engine failed to relight due to the aircraft's high altitude when the relight was attempted.

15. Because there were no timely ECAM warnings of automatic fuel transfer failures, the flight crew invoked the 'TRIM TANK FUEL UNUSEABLE' procedure from the QRH.

16. The flight crew perceived that the TRIM TANK FUEL UNUSEABLE' procedure was not working because no fuel transfer arrows were displayed on the ECAM fuel SD page and significant changes to the quantity indications were not easily identified.

17. When the flight crew perceived that fuel was not transferring manually, they resorted to iterative use of other fuel transfer failure procedures listed in the FCOM compendium of emergency procedures.

18. ATC communications were good.

19. The FDR sampling rate of FCMC faults meant that it was possible for a fault lasting up to three seconds not being recorded.

20. Automatic fuel transfer ceased at 1934 hrs which was almost 8 hours before No 1 engine lost power.

21. The automatic fuel transfers stopped due to a failure of the discrete outputs from the master FCMC.

22. After 1934 hrs, the fuel remaining in Inner fuel tanks 1, 2, 3 and 4 became the only fuel usable by each engine respectively, until the selection of manual fuel transfers.

23. There were no fuel system related flight warnings following the failure of the automatic fuel transfer system.

24. Failure of the automatic fuel transfer system did not result in the aircraft's CG position exceeding the in-flight limits.

25. Total fuel quantity (as opposed to useable fuel quantity in the engine feed tanks) continued to be displayed on the SD fuel status page.

26. The flight crew did not recall seeing any amber on the fuel system display page throughout the flight.

27.	The selection of the fuel cross feed valves prevented the complete rundown of No 4 engine.

28.	Bench tests of FCMC1 and FCMC2 did not reveal any faults.

29.	Bench tests of FDC1 and FDC2 did not reveal any faults.

30.	The lack of fuel system flight warnings was due to a failure of the ARINC output buses A and B from the master FCMC.

31.	A failure of both FWCs did not occur.

32.	Bench tests of FWC1 and FWC2 did not reveal any faults.

33.	Bench tests of SDAC1 and SDAC2 did not reveal any faults.

34.	The FDC would have generated a low fuel quantity discrete, triggered at a fuel level below that for which a low fuel level signal was generated by the FCMC.

35.	Because total fuel quantity was being displayed on the ECAM fuel SD page, at least one FCMC was still delivering an output.

36.	The FWCs disregarded the FDC low fuel level discrete (the alternate or back-up warning signal) because one FCMC was still delivering an output.

37.	FCMC2 was most likely the master FCMC at 1934 hrs.

38.	The slave FCMC (probably FCMC1) may have had a lower health level, due to previous failures, than the master FCMC at 1934 hrs.

39.	The slave FCMC was not able to take control as master FCMC due to its lower health status.

40.	The slave FCMC was still outputting fuel quantity data on its ARINC output buses A and B.

41.	The failure of the ARINC output buses A and B from the master FCMC caused a lack of fuel transfer arrows on the ECAM SD fuel display following the operation of manual fuel transfers.

42. The PFR and TSD, albeit with limitations, proved invaluable in this investigation.

43. The PFR limitations prevented a full determination of fault frequency and reasons for fault indications during the incident flight.

44. The FCMC TSD only recorded the last eight detected faults in its memory, limiting a determination of the first failure events.

45. The presentation of FWC and DMC TSD in hexadecimal code was difficult to interpret and required the aircraft manufacturer to decode the data.

46. 'FCMC1(2) FAULT' indications were common occurrences.

47. The reason for frequent 'FCMC1(2) FAULTS' was disagreements between the COM and MON processes created by asynchronous processor clocks.

48. There was an aircrew operational notice which removed the requirement for crews to make a technical log entry for a single FCMC failure with successful reset during flight.

49. Maintenance action following a 'FCMC1(2) FAULT' was to carry out a reset and BITE test. If this was satisfactory the aircraft was dispatched.

50. G-VATL had suffered a long term fault with the Inner 4 tank temperature sensor, later found to be due to a loose connector.

51. EASA CS-25 does not require an independent low fuel level warning system.

52. EASA CS-23, CS-27 and CS-29 all require independent low fuel level warnings.

(b)   **Causal Factors**

The investigation determined the following causal factors that led to the starvation of fuel tanks Inner 1 and 4 and the subsequent rundown of engine number 1 and number 4.

1.   Automatic transfer of fuel within the aircraft stopped functioning due to a failure of the discrete outputs of the master Fuel Control and Monitoring Computer (FCMC).

2.   Due to FCMC ARINC data bus failures, the flight warning system did not provide the flight crew with any timely warnings associated with the automated fuel control system malfunctions.

3.   The alternate low fuel level warning was not presented to the flight crew because the Flight Warning Computer (FWC) disregarded the Fuel Data Concentrator (FDC) data because its logic determined that at least one FCMC was still functioning.

4.   The health status of the slave FCMC may have been at a lower level than that of the master FCMC, thus preventing the master FCMC from relinquishing control of the fuel system when its own discrete and ARINC outputs failed.

4   Safety Recommendations

The following safety recommendations were made:

4.1   **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.

4.2   **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.

4.3   **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).

4.4   **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).

4.5   **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).

4.6   **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).

5 Responses to Safety Recommendations and actions taken

5.1 Airbus response to Safety Recommendations 2005-36 and 2005-37

Airbus formally responded to these recommendations on 25 May 2005. Arising from the first recommendation, the company had launched modifications that they considered went beyond the spirit of the recommendations. Changes to the FCMC software and logic systems were being implemented including changes to the logic of the MON process which would be delivered in software standard FL 8. In respect of the second recommendation, an independent FWC 'Fuel Low Level Warning' was being developed.

These initial responses were clarified in February 2007. Three separate modifications have been identified and have been made available for fleet embodiment by Service Bulletin (SB). These SBs are as follows.

SB A340-28-5033

This SB embodies an FCMC software upgrade commonly known as FL 8.1 (Flight Load 8.1). This upgrade was launched as an Airbus monitored retrofit on 14 November 2005. It was managed by Airbus and all of the A340-500/600 fleet now has FL 8.1 or a later standard embodied.

SB A340-28-5031

This SB introduces aircraft wiring to connect additional ARINC low level sensing signals directly from both FDCs to the FWCs, ensuring that the low level warning can be issued to the crew in the event of an FCMC failure or malfunction. This SB was launched as an Airbus monitored retrofit on 14 November 2005.

SB A340-31-5022

This SB was launched as an Airbus monitored retrofit on 14 November 2005. The SB modifies the FWC software standard to FWC W4-1. It includes changes to enable the fuel low-level warning to be triggered from either the FCMC or from directly wired low-level sensing signals provided by SB A340-28-5031. To enable this FCMC independent low-level warning, both this SB and SB A340-28-5031 are necessary to enable the low level warning in the event of an FCMC failure or malfunction.

Airbus stated that these SBs have been discussed with EASA and the intention is to mandate the embodiment of all three modifications.   It is proposed that a two year period is permitted from issue of the Airworthiness Directive/Compliance Notice to allow the fleet to be modified. Until embodiment of these modifications, the OEBs[14] (62-1 and 63-1) issued shortly after the event will remain valid, (these OEBs are cancelled by embodiment of the three SBs).

5.2   Response to Safety Recommendations 2005-108 and 2005-109

Initially the EASA did not respond to these safety recommendations. However, soon after they were formally made, the AAIB discovered that its Italian counterpart, the Agenzia Nazionale per la Sicurezza del Volo (ANSV), had issued a comparable safety recommendation arising from its investigation into an accident to ATR-72 TS-LBB on 6 August 2005 offshore of Palermo Airport. The recommendation was as follows:

> *ANSV-13/443-05/3/A/05*
>
> *The European Aviation Safety Agency should consider the possibility to change the fuel system certification regulation for public transport aircraft, in order to require that the fuel low level warnings be independent from the fuel gauging systems.*

The Irish Air Accident Investigation Unit (AAIU) had also made a comparable safety recommendation arising from their investigation into a serious incident involving an in-flight engine failure due to fuel starvation. The recommendation was as follows:

> *AAIU Safety Recommendation 10 of 2005*
>
> *The European Air Safety Agency (EASA) should review the certification criteria for public transport aircraft low fuel contents warning systems, with a view to requiring such systems to be independent of the main contents gauging systems.*

Once the existence of these three, broadly similar, safety recommendations was evident, further liaison between the EASA and the AAIB produced a formal response from the EASA which was received by the AAIB on 2 October 2006. The Agency's reply stated:

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14   Operations Engineering Bulletins. These are temporary leaflets inserted into Flight Crew Operating Manuals to address safety significant issues pending the incorporation of formal modifications into the Manuals.

The Agency agrees with the safety recommendation. Consequently a task has been added to the advance planning of the Agency's rulemaking programme. This is to be called "25.055 – fuel system low level indication/fuel exhaustion". The plan is to set-up a working group and to publish a Notice of Proposed Amendment (NPA) by the 4th Quarter 2007. This is to be done with the aim of amending the certification specification CS-25 by 1st Quarter 2009.

5.3   Response to Safety Recommendations 2005-110 and 2005-111

On 8 May 2006 the AAIB received the US Federal Aviation Administration (FAA) response to Safety Recommendations 2005-110 and 2005-111. The Adminstration classified the recommendations as:

06.006 (2005-110) "Closed Acceptable Alternate Action"
06.007 (2005-111) "Closed – Not Adopted"

This position was adopted before EASA had responded to the equivalent Safety Recommendations 2005-108 and 2005-109.

In 1987 the Administration had prepared a Notice of Proposed Rulemaking (NPRM) entitled *'Low Fuel Quantity Alerting System Requirements for Transport Category Airplanes'*. This NPRM was not adopted and it was withdrawn in August 2002 in the interests of harmonising international certification requirements.

Appendix Q contains the response from the FAA to recommendations 2005-110 and 2005-111 and more information regarding the NPRM.

J J Barnett
Inspector of Air Accidents
Air Accident Investigation Branch
Department for Transport
July 2007

QRH Abnormal Procedures TRIM TANK FUEL UNUSEABLE

virgin atlantic A340-600	ABNORMAL PROCEDURES	REV 21 SEQ 105	2.10

TRIM TANK FUEL UNUSABLE

T TK XFR . . . . .FWD
T TK FEED . . . . OPEN

● **If TRIM TANK FUEL still unusable**
   — OUTR TK XFR . . . . ON
   — CTR TO INR L and R . . . . OFF
   — CTR AFT XFR L and R . . . . OFF
   MAXIMUM FLIGHT TIME . . . . 4 HOURS
   After 4 hours, depending on the fuel distribution, the aft CG limit may be
   reached.

   | **FOR LANDING** |

● **If CG > aft CG limit shown below :**
   — APPR SPD . . . . VLS + 10 KT
R   — LDG DIST PROC . . . . APPLY
R   Refer to the QRH part 2, or to the FCOM 3.02.80.
R

FCOM - FUEL Trim Tank Transfer Fault Procedure

virgin atlantic A340-600 Flight Crew Operating Manual	ABNORMAL AND EMERGENCY FUEL	3.02.28A	P 10
		SEQ 100	REV 25

FUEL T TK XFR FAULT

Either aft or forward transfer has failed. This caution is recalled, if the center tank fuel quantity threshold reaches 34 tons.

● WHEN CTR TK < 34 T (a) :
  – T TK XFR... FWD
    Fuel consumption increases by approximately 2 %.
● WHEN T TK EMPTY :
  – T TK XFR ....AUTO
  – T TK FEED .... ISOL
● If manual transfer fails :
  – T TK FEED .... OPEN
    Trim tank fuel is transferred by gravity.
  – T TK XFR..AUTO
  ● WHEN T TK EMPTY
    – T TK FEED .... ISOL
● If T TK FEED OPEN selection fails to initiate the transfer
  – T TK FEED .... ISOL
  T TK UNUSABLE
  – T TK UNUSBL PROC...APPLY

STATUS

APPR PROC   **INOP SYS**
  ● AT SLATS EXTENSION :   T TK XFR
    – T TK XFR.. AUTO
    – T TK FEED .... AUTO
      Manual forward transfers must be stopped at slats' extension, to avoid CG changes during approach.
  T TK UNUSABLE
  – T TK UNUSABLE PROC .... APPLY

(a) If both trim tank transfer pumps have failed, this line is replaced by :
  WHEN SPD > 270 KT AND NOT IN CLIMB AND CTR TK < 34 T

FCOM - FUEL Centre/Inner Transfer Fault Procedure

virgin atlantic ✈ A340-600 Flight Crew Operating Manual	ABNORMAL AND EMERGENCY FUEL	3.02.28A SEQ 100	P 9 REV 25

FUEL CTR/INR XFR FAULT

This caution is triggered, if an anomaly is detected during the center to inner tank transfer, and recalled when the inner tank fuel quantity threshold reaches 14 tons.

● WHEN INR 1 < 14 T AND INR 4 < 14 T :
  – CTR TO INR XFR..MAN
  CTR TK UNUSABLE IF < 35 T
● WHEN CTR TK EMPTY :
  – CTR TO INR XFR...AUTO

STATUS

CTR/INR XFR : MAN ONLY
CTR TK UNUSABLE IF < 35 T

FUEL OUTR TK XFR FAULT

This caution is triggered, if an anomaly is detected either before or during the outer to inner tank transfer.

– OUTR TK XFR...MAN
● If manual transfer fails :
  L(R) OUTR TK UNUSABLE
● WHEN R(L) (BOTH) OUTR EMPTY :
  – OUTR TK XFR...AUTO

STATUS

● If manual transfer fails :   **INOP SYS**
  L(R) OUTR TK UNUSABLE   L OUTR XFR
                                          R OUTR XFR

FUEL MAN XFR COMPLETED

Center tank, trim tank, or both outer tanks, are empty, and the manual XFR pushbuttons are ON.

– OUTR TK XFR...AUTO
– T TK XFR...AUTO
– CTR TO INR XFR..AUTO

VI6 MSN ALL

Fuel Status Display - Data Sources

Display item	FCMC – Normal operation	SDAC - If both FCMC fail OR Master FCMC has no output and remaining FCMC is slave.
LP Valve	Master	YES
Crossfeed valve	Master	YES
Crossfeed pipe	Calculated internal to DMC based on valve info from Master FCMC.	Calculated internal to DMC based on valve info from SDAC
Engine pump	Master	YES
Standby engine pump	Master	YES
Engine pump Low Pressure	Master	YES
Inner tank aft transfer pump	Master	NO
Centre tank pump	Master	YES
Centre tank transfer pumps	Master	YES
Trim tank transfer pumps.	Master	YES
Outer tank fuel quantity	Master or Slave FCMC	NO
Collector cell fuel quantity	Master	NO
Inner tank fuel quantity	Master or Slave FCMC	NO
Centre tank fuel quantity	Master or Slave FCMC	NO
Trim tank fuel quantity	Master or Slave FCMC	NO
Inner 1 or 2 fuel transfer arrow	Master	NO
Outer tank fuel unusable	Master	NO
Centre tank fuel partially usable	Master	NO
Inner 2 or 3 partially usable	Master	NO
Trim tank fuel unusable	Master	NO
Fuel on Board	Master or Slave FCMC	NO
Outer tank fuel temperature	Master or Slave FCMC	NO
Inner tank fuel temperature	Master or Slave FCMC	NO
Trim tank fuel temperature	Master or Slave FCMC	NO
Outer to Inner and centre to inner fuel transfer arrows.	Master	NO
Centre to inner 1 or 4 fuel transfer arrow	Master	NO
Trim tank to inner tank fuel transfer	Master	NO
Trim tank to centre tank fuel transfer arrow	Master	NO
Jettison arrows	Master	YES
APU fuel feed indication.	Master	YES

Figure 1 Fuel System Pump and Valve Schematic

1 - PUMP MAIN FUEL ENGINE 1
2 - PUMP STBY FUEL ENGINE 1
3 - PUMP MAIN FUEL ENGINE 2
4 - PUMP STBY FUEL ENGINE 2
5 - PUMP MAIN FUEL ENGINE 3
6 - PUMP STBY FUEL ENGINE 3
7 - PUMP MAIN FUEL ENGINE 4
8 - PUMP STBY FUEL ENGINE 4
9 - PUMP AFT TRANSFER 1
10 - PUMP AFT TRANSFER 2
11 - PUMP AFT TRANSFER 3
12 - PUMP AFT TRANSFER 4
13 - PUMP APU FUEL
14 - PUMP LEFT CENTRE TANK TRANSFER
15 - PUMP RIGHT CENTRE TANK TRANSFER
16 - PUMP LEFT AFT CENTRE TANK TRANSFER
17 - PUMP RIGHT AFT CENTRE TANK TRANSFER
18 - PUMP LEFT TRIM TRANSFER
19 - PUMP RIGHT TRIM TRANSFER

A - VALVE FUEL CROSSFEED 2
C - VALVE FUEL CROSSFEED 1
E - VALVE FUEL CROSSFEED 3
F - VALVE FUEL INLET INNER TANK 2
G - VALVE FUEL INLET CENTER TANK
GG - VALVE REFUEL, RESTRICTOR CENTER TANK
H - VALVE FUEL INLET INNER TANK 3
J - VALVE APU LOW PRESSURE
K - VALVE APU ISOLATION
L - VALVE FUEL INLET TRIM TANK
M - VALVE FUEL INLET LEFT OUTER TANK
N - VALVE FUEL INLET RIGHT OUTER TANK
P - VALVE INTERTANK FUEL TRANSFER RIGHT
Q - VALVE INTERTANK FUEL TRANSFER LEFT
R - VALVE REFUEL ISOLATION LEFT
S - VALVE REFUEL ISOLATION RIGHT
T - VALVE FUEL TRIM TANK ISOLATION
V - VALVE FUEL AUXILIARY FORWARD TRANSFER
W - VALVE FUEL TRIM PIPE ISOLATION
X - VALVE FUEL JETTISON LEFT
Y - VALVE FUEL JETTISON RIGHT 2
Z - VALVE FUEL CROSSFEED 4
BA - VALVE FUEL INLET INNER TANK 1
BB - VALVE FUEL INLET INNER TANK 4
BC - VALVE FUEL TRANSFER INNER TANK 1
BD - VALVE FUEL TRANSFER INNER TANK 4
BG - VALVE FUEL TRANSFER INNER TANK 2
BH - VALVE FUEL TRANSFER INNER TANK 3
BM - VALVE AUXILIARY REFUEL
BN - VALVE DEFUEL
EC - VALVE TRANSFER CONTROL INNER TANK 2
ED - VALVE TRANSFER CONTROL INNER TANK 3
1 - VALVE FUEL LP ENGINE 1
2 - VALVE FUEL LP ENGINE 2
3 - VALVE FUEL LP ENGINE 3
4 - VALVE FUEL LP ENGINE 4

Pumps, Valves & Switches Commanded By FCMC Discrete Outputs

The table below lists the pumps, valves and switches directly commanded by the master FCMC.

Pumps commanded by FCMC Discrete.
Inner tank 1 aft transfer pump (9)
Inner tank 2 aft transfer pump (10)
Inner tank 3 aft transfer pump (11)
Inner tank 4 aft transfer pump (12)
Centre tank left transfer pump (14)
Centre tank right transfer pump (15)
Centre tank left aft transfer pump (16)
Centre tank right aft transfer pump (17)
Trim tank left transfer pump (18)
Trim tank right transfer pump (19)
Valves commanded by FCMC discrete.
Inner tank 1 inlet valve (BA)
Inner tank 4 inlet valve (BB)
Inner tank 1 transfer valve (BC)
Inner tank 4 transfer valve (BD)
Inner tank 2 transfer valve (BG)
Inner tank 3 transfer valve (BH)
Auxiliary refuel valve (BM)
Defuel valve (BN)
Inner tank 2 transfer control valve (EC)
Inner tank 3 transfer control valve (ED)
Inner tank 2 inlet valve (F)
Centre tank inlet valve (G)
Centre tank restrictor valve (GG)
Inner tank 3 inlet valve (H)
Trim tank inlet valve (L)
Left outer tank inlet valve (M)
Left outer tank inlet valve (M)
Right outer tank inlet valve (N)
Right intertank transfer valve (P)
Left intertank transfer valve (Q)
Refuel isolation valve (R,S)

Valves commanded by FCMC discrete.
Trim tank isolation valve (T)
Auxiliary forward transfer valve (V)
Trim pipe isolation valve (W)
left jettison valve (X)
Right jettison valve (Y)
Overhead Panel switches commanded by FCMC discrete.
Centre tank left aft transfer pump push button fault caption
Centre tank left transfer pump push button fault caption
Centre tank right aft transfer pump push button fault caption
Centre tank right transfer pump push button fault caption
Centre tank transfer override push button fault caption
Inner tank 1 aft transfer pump push button fault caption
Inner tank 2 aft transfer pump push button fault caption
Inner tank 3 aft transfer pump push button fault caption
Inner tank 4 aft transfer pump push button fault caption
Outer tank transfer override pushbutton fault caption
Trim tank left transfer pump push button fault caption
Trim tank manual override pushbutton fault caption
Trim tank right transfer pump push button fault caption

FDC/FCMC FAULT FCOM Procedure

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FUEL FDC 1(2) FAULT

Failure of one Fuel Data Concentrator (FDC).

Crew awareness.

STATUS

INOP SYS
FDC 1(2)

FUEL FCMC 1(2) FAULT

Failure of one Fuel Control Monitoring Computer (FCMC).

Crew awareness.

STATUS

INOP SYS
FCMC 1(2)

FUEL FCMC 1+2 FAULT

Transfers are controlled using the T TK XFR, OUTR TK XFR and CTR TK XFR pushbuttons.

– FCMC 1 + 2 ....RESET
– WEIGHT/CG...INITIALIZE

    In flight, after a dual FCMC reset, the weight and CG displayed on the FUEL PRED page are those computed by the flight envelope part of the FMGC (FE).

    The GW and CG will be re-initialized, if the FCMC reset is successful.

FUEL XFR : MAN ONLY

– ESTIMATE FOB BY F. USED

    MCDU FUEL PRED page data is no longer valid. So, the FOB shall be estimated by using the Fuel Used information.

● WHEN FOB < 100 T :

    – T TK XFR.. FWD

      Fuel consumption increased by approximately 2 %.

    – CTR TO INR XFR...MAN

    – OUTR TK XFR...MAN

⇩

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FUEL FCMC 1+2 FAULT (CONT D)

STATUS

APPR PROC
   ● AT SLATS EXTENSION :
    – T TK XFR...AUTO
       Manual trim tank transfer must be stopped at slats' extension, to
       avoid CG changes during approach.
FUEL XFR : MAN ONLY

INOP SYS
FCMC 1+2
JETTISON

FUEL WEIGHT/CG DISAGREE

This caution is triggered, in case of disagreement between the ZFW or ZFCG values from FMGC 1 and 2.

– FMGC VALUES..INITIALIZE
   Confirm that the ZFW and ZFCG values from each FMGC are the same as the loadsheet values.

FUEL ABNORM MAN FWD XFR

This warning is triggered, to avoid an inadvertent aft transfer, when the T TK XFR pushbutton is selected FWD, or when the TRIM TANK FEED selector is set to OPEN, if :
–The trim tank pumps are failed or OFF, and
–The aircraft pitch attitude is above 3.4 degrees for more than 30 seconds.
This warning is not triggered, in case of an inner tank low level, or in case of an AFT CG warning.

– T TK FEED ....AUTO
● If normal configuration is recovered :
   – T TK FEED .... OPEN

STATUS

– LVL OFF FOR MAN FWD XFR

FUEL NO WEIGHT/CG DATA

This caution is triggered at engine start, if no WEIGHT/CG has been entered by the crew, or following a reset of both FCMCs.

– WEIGHT/CG..INITIALIZE

FCOM - ENG 1(2)(3)(4) FAIL procedure

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		SEQ 040	REV 23

ENG 1 (2)(3)(4) FAIL

An engine flame-out may be recognized by a rapid decrease in EGT, N3, FF, followed by a decrease in N1.
Engine damage may be accompanied by :
–Explosions,
–Significant increase in aircraft vibrations and/or buffeting,
–Repeated or uncontrollable engine stalls,
–Associated abnormal indications such as hydraulic fluid loss, or no N2 or N3 indication.

■ **In case of N1 shaft rupture :**
  SHAFT FAILURE
  FADEC automatically shuts down the engine.
  – THR LEVER (affected engine) ....IDLE
  – ENG MASTER (affected engine).. OFF
    On ground, after 15 minutes, the FADEC is no longer supplied. So, the THR LEVER........IDLE line reappears, even if the thrust lever is at idle.

■ **In case of FADEC overheat :**
  FADEC OVHT
  FADEC automatically shuts down the engine.
  – THR LEVER (affected engine) ....IDLE
  – ENG MASTER (affected engine).. OFF

■ **In case of a thrust malfunction :**
  THRUST MALFUNCTION
  On ground, an overthrust condition is detected by the FADEC, which automatically shuts down the engine.
  – THR LEVER (affected engine) ....IDLE
  – ENG MASTER (affected engine).. OFF

■ **Before takeoff or after landing**
  – THR LEVER (affected engine) ....IDLE
  – ENG MASTER (affected engine).. OFF
    On ground, after 15 minutes, the FADEC is no longer supplied. So, the THR LEVER .... IDLE line reappears, even if the thrust lever is at idle.
  ● **IF DAMAGE :**
    – ENG FIRE P/B (affected engine) ....PUSH
      With ENG FIRE pushbutton pushed, FADEC is not longer supplied. So, the THR LEVER .... IDLE line reappears, even if the thrust lever is at idle.
    – AGENT 1 .... DISCH
    – INR TK SPLIT 2 .... ON
    – INR TK SPLIT 3 .... ON

⇩

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		SEQ 040	REV 26

ENG 1 (2)(3)(4) FAIL (CONT D)

● IF NO DAMAGE :
– ENG (affected) RELIGHT ....CONSIDER

ENG 1 (2)(3)(4) SHUT DOWN

Apply ENG SHUT DOWN procedure if damage, or if engine relight is unsuccessful.

Note:- (i) It is VAA policy to always assume engine damage with a failure occurring on take-off or go-around where the thrust levers are in the TOGA or FLEX gate.

■ **In flight**
– ENG START SEL .... IGN
  Selection of continuous ignition confirms the FADEC's immediate relight attempt.
– THR LEVER (affected engine) ....IDLE

  Note : In case of EGPWS alerts, reduce speed with care below VLS with flaps extended (at light weights VMC may be reached before α max), when applying the EGPWS procedure.

● IF NO RELIGHT AFTER 30 S :
– ENG MASTER (affected engine) .... OFF
● IF DAMAGE :
– ENG FIRE P/B (affected engine) ....PUSH
  With the ENG FIRE pushbutton pushed, the FADEC is not longer supplied. So, the THR LEVER IDLE line reappears, even if the thrust lever is at idle.
– AGENT 1 AFTER 10 S .... DISCH
– INR TK SPLIT 2 .... ON
– INR TK SPLIT 3 .... ON
● IF NO DAMAGE :
– ENG (affected) RELIGHT ....CONSIDER
  Apply the ENG RELIGHT (in flight) procedure.

ENG 1 (2)(3)(4) SHUT DOWN
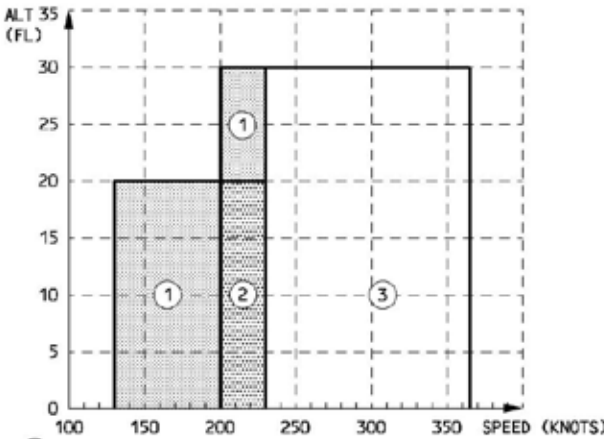
Apply ENG SHUT DOWN procedure if damage, or if engine relight is unsuccessful.
If high engine vibration occurs and continues after engine shutdown, reduce airspeed and descend to a safe altitude.
Attempt to define and use a practical airspeed and altitude for minimum vibrations.
Landing is in CONF 3 for performance reasons.
CONF 3 should be selected as the landing configuration on the MCDU.

QRH Abnormal Procedures Engine Relight (in flight)

	ABNORMAL PROCEDURES	REV 22	**2.26**
		SEQ 150	

ENG RELIGHT (in flight)

MAX GUARANTEED ALTITUDE .... 30000 FT
– ENG MASTER (affected engine) .... OFF
– THR LEVER (affected engine) .... check IDLE
– MAN START pushbutton (affected engine) .... OFF

Autostart is recommended in flight.
Be aware that, contrary to autostart on ground, the crew must take appropriate action in case of an abnormal start.

– ENG START SEL .... IGN
– X BLEED .... OPEN
– WING ANTI ICE (For starter-assisted start) .... OFF

The FADEC will select an assisted start when N3<7%.
Flying at, or above, 230 knots ensures a windmilling start.

– ENG MASTER (affected engine) .... ON

Engine light-up must be achieved within 30 seconds after fuel flow increases.
– Monitor N3.
– If uncertain about successful relight, move the thrust lever forward and check engine response.

R ■ **When idle reached (AVAIL indication pulses in green) :**
　　– ENG START SEL .... NORM
　　– TCAS MODE SEL .... check TA/RA

　　　Check that the selector is at TA/RA since, if the ENG SHUT DOWN procedure has been applied, the TCAS mode selector may have been set to the TA position.

　　– Affected SYS .... RESTORE

■ **If no relight :**
– ENG MASTER (affected engine) .... OFF
R

(1) STARTER-ASSISTED.
(2) STARTER-ASSISTED OR WINDMILLING QUICK RELIGHT.
(3) STABILIZED WINDMILLING START.

RR Eng : All

Mod : 50968
FADEC 14.1.3 : windmilling above 230 kts, instead of 250 kts

FCLS-00-D002-026-A150AA

Flight Data Recorder Graphs
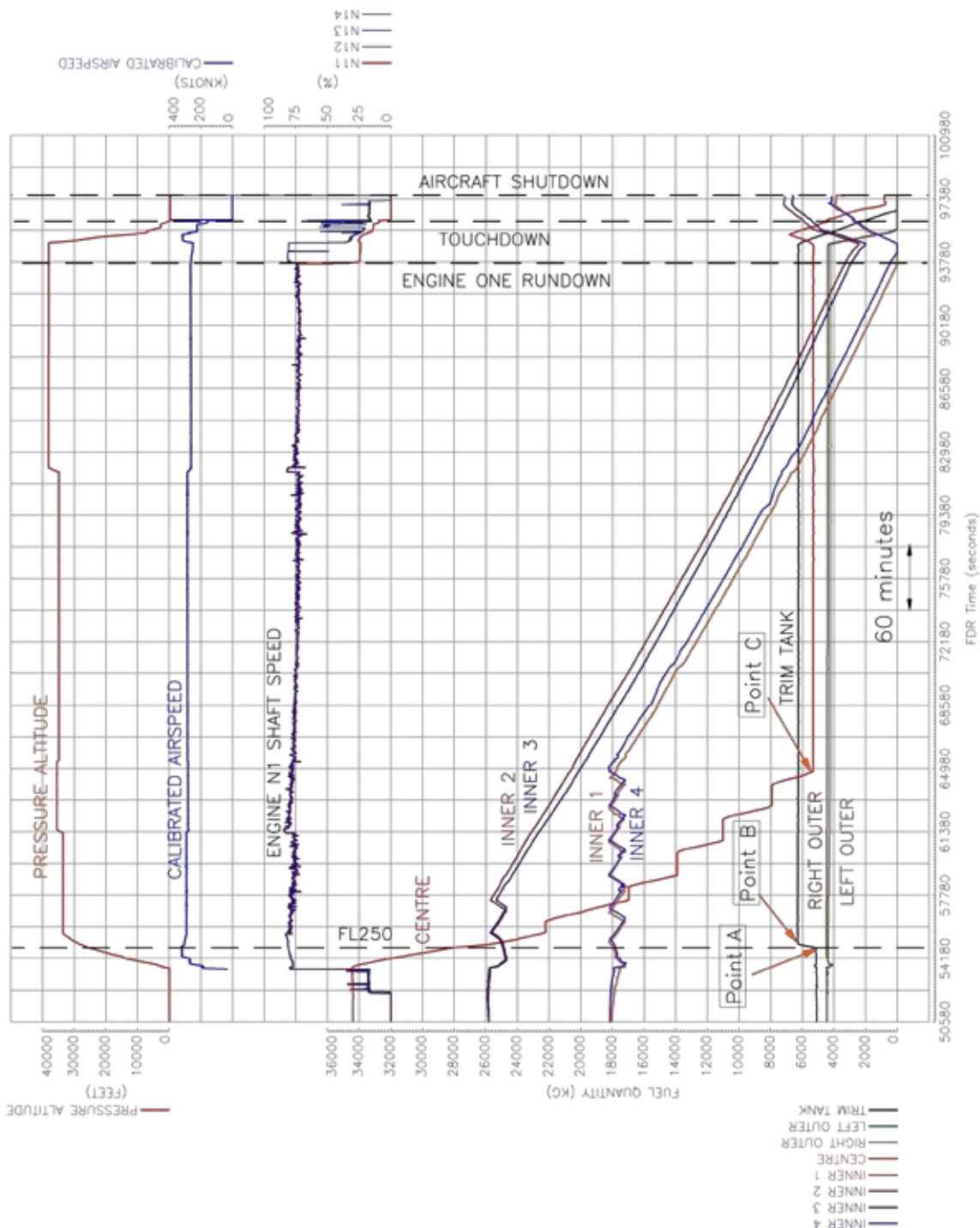
Figure 1
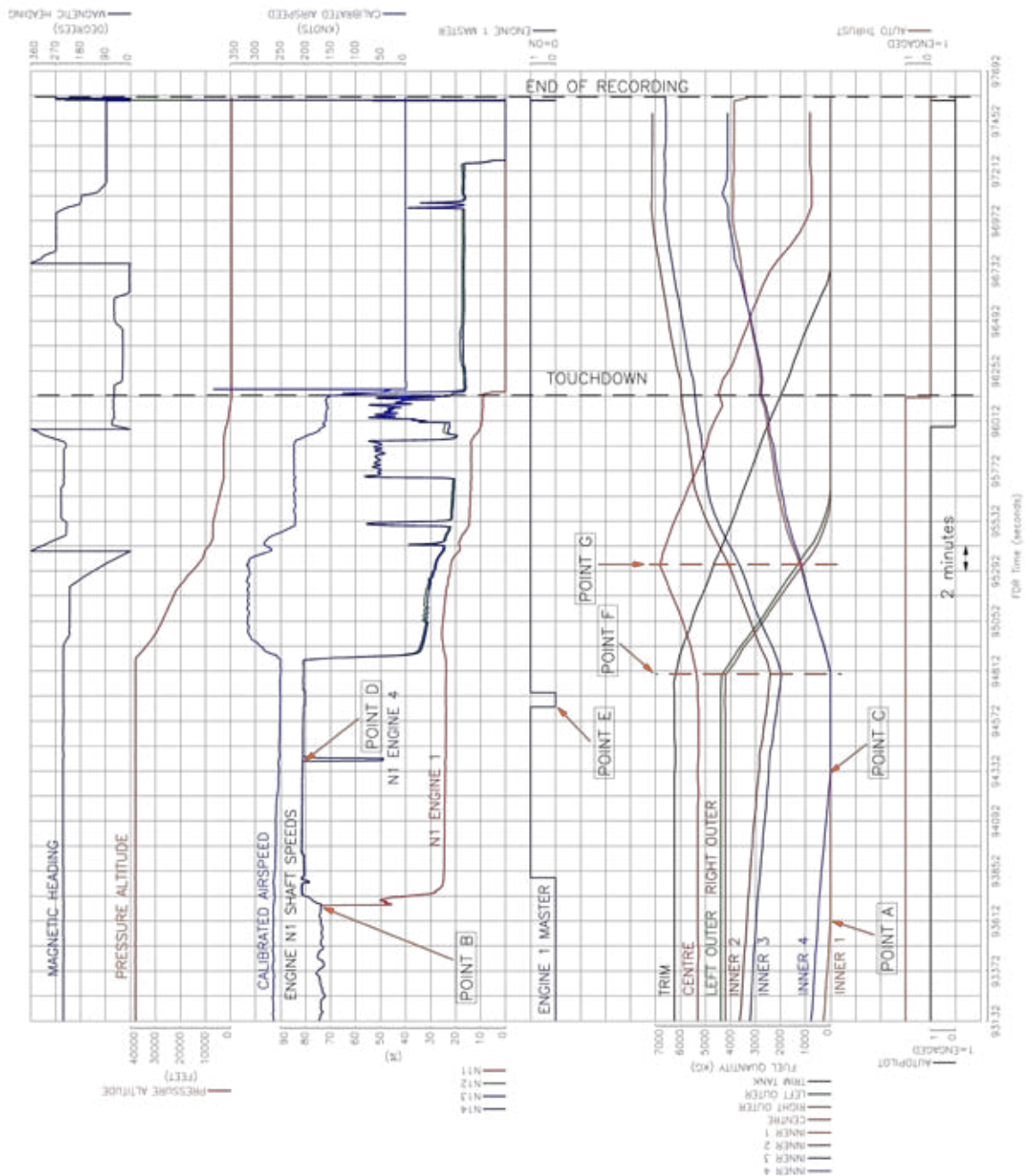
Figure 2
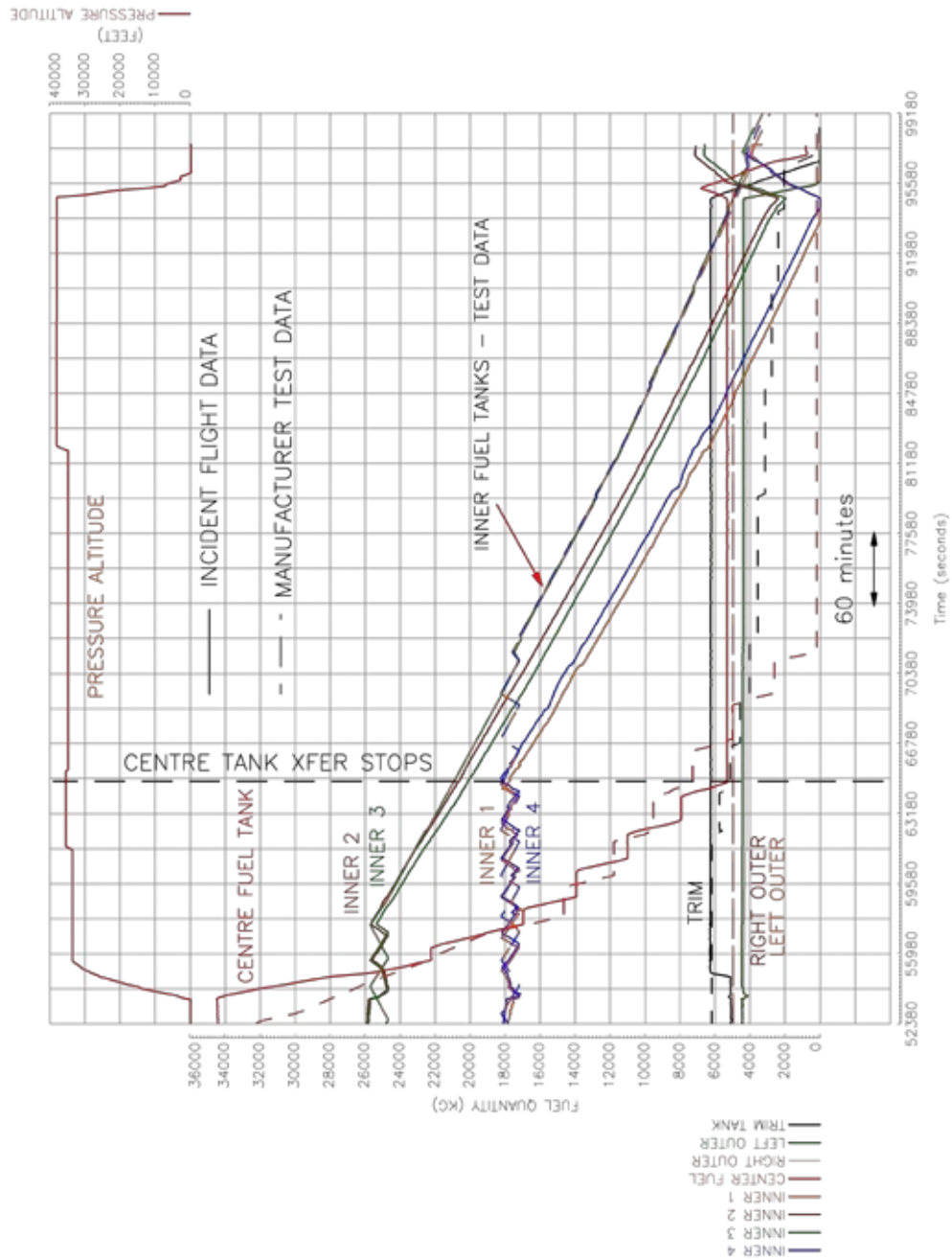
Figure 3

FCMCs Troubleshooting Data

```
A/C IDENT  G-VATL                                              CMC1 PRINTING
DATE       FEB07              MAINTENANCE
FLT NBR    VIR201          SYSTEM REPORT/TEST                  PAGE 01/05
FROM/TO    VHHH/EHAM             FCMC1                         DATE FEB08
START/END  1621/0413       TROUBLE SHOOTING DATA               UTC  0954


                    1/34                                 2/34
        DATE   UTC   ZONE    OCC         DATE   UTC   ZONE    OCC
        FEB08  0411  LAST LEG 3          FEB08  0411  LAST LEG 3
        FLIGHT PHASE: 09                 FLIGHT PHASE: 09
        SOURCE: FCMC1 CMP                SOURCE: FCMC1 CMP
        FUEL INR 3 XFR CNTRL VLV         FUEL INR 2 XFR CNTRL VLV
        (6100L2)                         (6100L1)

        FAILED SHUT                      FAILED SHUT
        6200 0000 0000 0000 0000         60F0 0000 0000 0001 0000
        0000 0000 0000 0000 0000         0000 0000 0000 0001 0000

                    3/34                                 4/34
        DATE   UTC   ZONE    OCC         DATE   UTC   ZONE    OCC
        FEB07  1934  LAST LEG 2          FEB07  1934  LAST LEG 1
        FLIGHT PHASE: 06                 FLIGHT PHASE: 06
        SOURCE: FCMC1 CMP                SOURCE: FCMC1 CMP
        REFUEL AUX VALVE(5210U)          FCMC2(5QM2)


                                         FCMC ALT HEALTH MISMATCH
        FAILED SHUT                      3020 0000 0000 0001 0000
        4130 0000 0000 0000 0000         0000 0000 0000 0001 0000
        0000 0000 0000 0000 0000

                    5/34                                 6/34
        DATE   UTC   ZONE    OCC         DATE   UTC   ZONE    OCC
        FEB07  1934  LAST LEG 1          FEB07  1934  LAST LEG 2
        FLIGHT PHASE: 06                 FLIGHT PHASE: 06
        SOURCE: FCMC1 CMP                SOURCE: FCMC1 CMP
        FUEL CTR TK R XFR PUMP           FUEL CTR TK L XFR PUMP
        (6000L2)                         (6000L1)

        FAILED OFF                       FAILED OFF
        23C0 0000 0000 0000 0000         4380 0000 0000 0001 0000
        0000 0000 0000 0000 0000         0000 0000 0000 0001 0000

                    7/34                                 8/34
        DATE   UTC   ZONE    OCC         DATE   UTC   ZONE    OCC
        FEB08  0228  LAST LEG 1          FEB08  0228  LAST LEG 1
        FLIGHT PHASE: 06                 FLIGHT PHASE: 06
        SOURCE: FCMC1 CMP                SOURCE: FCMC1 CMP
        FUEL R OUT TK INLET VLV          FUEL L OUT TK INLET VLV
        (5000U2)                         (5000U1)

        FAILED SHUT                      FAILED SHUT
        2190 0000 0000 0000 0000         2080 0000 0000 0000 0000
        0000 0000 0000 0000 0000         0000 0000 0000 0000 0000


                         CONTINUED
```

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┌─────────────────────────┬──────────────────────┬──────────────────┐
│ A/C IDENT   G-VATL      │                      │ CMC1 PRINTING    │
│ DATE      FEB07         │     MAINTENANCE      │                  │
│ FLT NBR   VIR201        │  SYSTEM REPORT/TEST  │ PAGE 02/05       │
│ FROM/TO   VHHH/EHAM     │        FCMC1         │ DATE FEB08       │
│ START/END 1621/0413     │ TROUBLE SHOOTING DATA│ UTC  0955        │
└─────────────────────────┴──────────────────────┴──────────────────┘
```

```
                    9/34                              10/34
DATE   UTC   ZONE   OCC            DATE   UTC   ZONE   OCC
FEB07  0618  PREV LEG 1           FEB07  0604  PREV LEG 1
FLIGHT PHASE: 06                  FLIGHT PHASE: 06
SOURCE: FCMC1 CMP                 SOURCE: FCMC1 CMP
POWER SUPPLY INTERRUPT            FCMC1(SQM1)


CP FCMS PSU INT > 220MS           ICP FDC2A RTD 6 FAIL
3080 0000 0000 0000 0000          3010 0000 0000 0003 0000
0000 0000 0000 0000 0000          0000 0000 2000 0003 0000

                    11/34                             12/34
DATE   UTC   ZONE   OCC            DATE   UTC   ZONE   OCC
FEB07  0530  PREV LEG 4           FEB06  1206  PREV LEG 4
FLIGHT PHASE: 06                  FLIGHT PHASE: 06
SOURCE: FCMC1 CMP                 SOURCE: FCMC1 CMP
FUEL INR TK 4 TEMP SNSR           FUEL INR TK 4 TEMP SNSR
(11QR2)                           (11QR2)


FQI TEMP AB COMPARE FAIL          FQI TEMP AB COMPARE FAIL
8530 0000 0000 0000 0000          8530 0000 0000 0003 0000
0000 0000 0000 0000 0000          2000 0000 0000 0003 0000

                    13/34                             14/34
DATE   UTC   ZONE   OCC            DATE   UTC   ZONE   OCC
FEB05  2151  PREV LEG 1           FEB05  2149  PREV LEG 4
FLIGHT PHASE: 02                  FLIGHT PHASE: 02
SOURCE: FCMC1 CMP                 SOURCE: FCMC1 CMP
FCMC1(SQM1)                       FUEL INR TK 4 TEMP SNSR
                                  (11QR2)


FUEL TEMP IND FAIL                FQI TEMP AB COMPARE FAIL
3012 0000 0000 0000 0000          8530 0000 0000 0003 0000
0000 0000 0000 0000 0000          0000 0000 0000 0003 0000

                    15/34                             16/34
DATE   UTC   ZONE   OCC            DATE   UTC   ZONE   OCC
FEB04  0511  PREV LEG 3           FEB03  2019  PREV LEG 1
FLIGHT PHASE: 02                  FLIGHT PHASE: 06
SOURCE: FCMC1 CMP                 SOURCE: FCMC1 CMP
FUEL INR TK 4 TEMP SNSR           POWER SUPPLY INTERRUPT
(11QR2)


FQI TEMP AB COMPARE FAIL          CP FCMS PSU INT > 220MS
8530 0000 0000 0000 0000          3080 0000 0000 0003 0000
0000 0000 0000 0000 0000          0000 0000 0000 0003 0000
```

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                    CONTINUED
```

```
A/C IDENT   G-VATL                                           CMC1 PRINTING
DATE        FEB07                    MAINTENANCE
FLT NBR     VIR201               SYSTEM REPORT/TEST           PAGE 03/05
FROM/TO     VHHH/EHAM                   FCMC1                 DATE FEB08
START/END   1621/0413           TROUBLE SHOOTING DATA         UTC  0956


                        17/34                                   18/34
         DATE   UTC   ZONE   OCC           DATE   UTC   ZONE   OCC
         FEB03  2018  PREV LEG 1           FEB02  2242  PREV LEG 4
         FLIGHT PHASE: 06                  FLIGHT PHASE: 06
         SOURCE: FCMC1 CMP                 SOURCE: FCMC1 CMP
         FCMC1(SQM1)                       FUEL INR TK 4 TEMP SNSR
                                           (11QR2)

         FUEL VALVE IND FAIL               FQI TEMP AB COMPARE FAIL
         3010 0002 0000 0000 0000          8530 0000 0000 002) 0000
         0000 0000 0000 0000 0000          0000 0000 0000 002) 0000

                        19/34                                   20/34
         DATE   UTC   ZONE   OCC           DATE   UTC   ZONE   OCC
         FEB02  0620  PREV LEG 2           FEB01  1609  PREV LEG 1
         FLIGHT PHASE: 06                  FLIGHT PHASE: 02
         SOURCE: FCMC1 CMP                 SOURCE: FCMC1 CMP
         FUEL INR TK 4 TEMP SNSR           FCMC1(SQM1)
         (11QR2)

         FQI TEMP AB COMPARE FAIL          FUEL TEMP IND FAIL
         4530 0000 0000 0000 0000          3012 0000 0000 000) 0000
         0000 0000 0000 0000 0000          0000 0000 0000 000) 0000

                        21/34                                   22/34
         DATE   UTC   ZONE   OCC           DATE   UTC   ZONE   OCC
         FEB01  1607  PREV LEG 3           FEB01  0956  PREV LEG 1
         FLIGHT PHASE: 02                  FLIGHT PHASE: 06
         SOURCE: FCMC1 CMP                 SOURCE: FCMC1 CMP
         FUEL INR TK 4 TEMP SNSR           POWER SUPPLY INTERRUPT
         (11QR2)

         FQI TEMP AB COMPARE FAIL          CP FCMS PSU INT > /20MS
         6530 0000 0000 0000 0000          3080 0000 0020 000| 0000
         0000 0000 0000 0000 0000          0000 0000 0000 000| 0000

                        23/34                                   24/34
         DATE   UTC   ZONE   OCC           DATE   UTC   ZONE   OCC
         FEB01  0812  PREV LEG 1           JAN31  1845  PREV LEG 4
         FLIGHT PHASE: 06                  FLIGHT PHASE: 06
         SOURCE: FCMC1 CMP                 SOURCE: FCMC1 CMP
         FCMC1(SQM1)                       FUEL INR TK 4 TEMP SNSR
                                           (11QR2)

         FUEL VALVE IND FAIL               FQI TEMP AB COMPARE FAIL
         3010 0000 0000 0000 0000          8530 0000 0000 000| 0000
         0000 0000 0000 0000 0000          0000 0000 0000 000| 0000


                              CONTINUED
```

```
A/C IDENT  .G-VATL              MAINTENANCE          CMC1 PRINTING
DATE     FEB07                SYSTEM REPORT/TEST     PAGE 04/05
FLT NBR  VIR201                    FCMC1 ··         DATE FEB08
FROM/TO  VHHH/EHAM           TROUBLE SHOOTING DATA   UTC  0957
START/END 1621/0413
```

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                    25/34                                26/34
   DATE   UTC   ZONE   OCC          DATE   UTC   ZONE   OCC
   JAN31  1204  PREV LEG 1          JAN31  0332  PREV LEG 4
   FLIGHT PHASE: 06                 FLIGHT PHASE: 06
   SOURCE: FCMC1 CMP                SOURCE: FCMC1 CMP
   REFUEL AUX VALVE(521QU)          FUEL INR TK 4 TEMP SNSR
                                    (110R2)

   FAILED OPEN                      FQI TEMP AB COMPAR  FAIL
   2130 0000 0000 0000 0000         8530 0000 0000 002  0000
   0000 0000 0000 0000 0000         0000 0000 0000 000  0000

                    27/34                                28/34
   DATE   UTC   ZONE   OCC          DATE   UTC   ZONE   OCC
   JAN30  1433  PREV LEG 1          JAN30  1427  PREV LEG 1
   FLIGHT PHASE: 06                 FLIGHT PHASE: 06
   SOURCE: FCMC1 CMP                SOURCE: FCMC1 CMP
   POWER SUPPLY INTERRUPT           FCMC1(SQM1)

   CP FCMS PSU INT > 220MS          FUEL TEMP IND FAIL
   3080 0000 0000 0000 0000         3010 0000 0000 0001 0000
   0000 0000 0000 0000 0000         0000 0000 0000 000  0000

                    29/34                                30/34
   DATE   UTC   ZONE   OCC          DATE   UTC   ZONE   OCC
   JAN30  1401  PREV LEG 4          JAN30  0444  PREV LEG 1
   FLIGHT PHASE: 06                 FLIGHT PHASE: 06
   SOURCE: FCMC1 CMP                SOURCE: FCMC1 CMP
   FUEL INR TK 4 TEMP SNSR          POWER SUPPLY INTERRUPT
   (110R2)

   FQI TEMP AB COMPARE FAIL         CP FCMS PSU INT > 220MS
   8530 0000 0000 0000 0000         3080 0000 0000 0001 0000
   0000 0000 0000 0000 0000         0000 0000 0000 0001 0000

                    31/34                                32/34
   DATE   UTC   ZONE   OCC          DATE   UTC   ZONE   OCC
   JAN30  0443  PREV LEG 1          JAN29  1558  PREV LEG 1
   FLIGHT PHASE: 06                 FLIGHT PHASE: 06
   SOURCE: FCMC1 CMP                SOURCE: FCMC1 CMP
   FCMC1(SQM1)                      POWER SUPPLY INTERRUPT

   FUEL VALVE IND FAIL              CP FCMS PSU INT > 220MS
   3010 0000 0000 0000 0000         3080 0000 0000 0001 0000
   0000 0000 0000 0000 0000         0000 0000 0000 0000 0000
```

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                        CONTINUED
```

```
+---------------------------+---------------------------+------------------+
| A/C IDENT   .G-VATL       |                           | CMC1 PRINTING    |
| DATE        FEB07         |      MAINTENANCE          |                  |
| FLT NBR     VIR201        |   SYSTEM REPORT/TEST      | PAGE 05/05       |
| FROM/TO     VHHH/EHAM     |        FCMC1              | DATE FEB08       |
| START/END   1621/0413     |   TROUBLE SHOOTING DATA   | UTC  0998        |
+---------------------------+---------------------------+------------------+
```

```
                        33/34                              34/34
         DATE   UTC   ZONE   OCC           DATE   UTC   ZONE   OCC
         FEB07  1631  CLASS 3  4           FEB07  1621  CLAS  3   1
         FLIGHT PHASE: 06                  FLIGHT PHASE: 03
         SOURCE: FCMC1 CMP                 SOURCE: FCMC1 CMP
         FUEL INR TK 4 TEMP SNSR           FUEL INR 1 TK FPM ) DENS
         (11QR2)                           (16SQT1)

         SENSOR B OPEN                     FQI DENSITY OUT-O '-RANGE
         8530 0000 0000 0000 0000          2450 0000 0000 00 )0 0000
         0000 0000 0000 0000 0000          0000 0000 0000 00 )0 0000
```

```
                        END OF REPORT
```

```
┌─────────────────────────────┬──────────────────────────────┬───────────────────┐
│ A/C IDENT  .G-VATL           │                              │ CMC1 PRINTING     │
│ DATE       FEB07             │        MAINTENANCE           │                   │
│ FLT NBR    VIR201            │     SYSTEM REPORT/TEST        │ PAGE 01/05        │
│ FROM/TO    VHHH/EHAM         │          FCMC2               │ DATE FEB08        │
│ START/END  1621/0413         │    TROUBLE SHOOTING DATA     │ UTC  1003         │
└─────────────────────────────┴──────────────────────────────┴───────────────────┘
```

```
                    1/37                              2/37
     DATE   UTC   ZONE    OCC           DATE   UTC   ZONE    OCC
     FEB08  0425  GROUND   1            FEB09  0425  GROUND   4
     FLIGHT PHASE: 09                   FLIGHT PHASE: 09
     SOURCE: FCMC2 CMP                  SOURCE: FCMC2 CMP
     FUEL CTR TK L XFR PUMP             FUEL INR TK 4 XFR VALVE
     (600QL1)                           (614QL4)

     FAILED OFF                         FAILED SHUT
     2390 0000 0000 0000 0000           81E2 0000 0000 0000 0000
     0000 0000 0000 0000 0000           0000 0000 0000 0000 0000


                    3/37                              4/37
     DATE   UTC   ZONE    OCC           DATE   UTC   ZONE    OCC
     FEB08  0425  GROUND   1            FEB08  0425  GROUND   1
     FLIGHT PHASE: 09                   FLIGHT PHASE: 09
     SOURCE: FCMC2 CMP                  SOURCE: FCMC2 CMP
     FUEL INR TK 3 XFR VALVE            FUEL INR TK 2 XFR VALVE
     (614QL3)                           (614QL2)

     FAILED SHUT                        FAILED SHUT
     21F0 0000 0000 0000 0000           20E0 0000 0000 0000 0000
     0000 0000 0000 0000 0000           0000 0000 0000 0000 0000


                    5/37                              6/37
     DATE   UTC   ZONE    OCC           DATE   UTC   ZONE    OCC
     FEB08  0347  LAST LEG 2            FEB08  0411  LAST LEG 1
     FLIGHT PHASE: 06                   FLIGHT PHASE: 09
     SOURCE: FCMC2 CMP                  SOURCE: FCMC2 CMP
     FUEL TRIM TK ISOL VALVE            FUEL INR 3 XFR CNTRL VLV
     (702QN)                            (610QL2)

     FAILED OPEN                        FAILED SHUT
     1170 0000 0000 0000 0000           8200 0000 0000 0000 0000
     0000 0000 0000 0000 0000           0000 0000 0000 0000 0000


                    7/37                              8/37
     DATE   UTC   ZONE    OCC           DATE   UTC   ZONE    OCC
     FEB08  0411  LAST LEG 1            FEB07  1941  LAST LEG 3
     FLIGHT PHASE: 09                   FLIGHT PHASE: 06
     SOURCE: FCMC2 CMP                  SOURCE: FCMC2 CMP
     FUEL INR 2 XFR CNTRL VLV           FUEL INR TK 1 XFR VALVE
     (610QL1)                           (614QL1)

     FAILED SHUT                        FAILED SHUT
     20F0 0000 0000 0000 0000           6000 0000 0000 0000 0000
     0000 0000 0000 0000 0000           0000 0000 0000 0000 0000
```

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                         CONTINUED
```

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┌─────────────────────────────┬──────────────────────────┬──────────────────┐
│ A/C IDENT  . G-VATL          │                          │ CMC1 PRINTING    │
│ DATE       FEB07             │      MAINTENANCE         │                  │
│ FLT NBR    VIR201            │   SYSTEM REPORT/TEST     │ PAGE 02/05       │
│ FROM/TO    VHHH/EHAM         │        FCMC2             │ DATE FEB08       │
│ START/END  1621/0413         │   TROUBLE SHOOTING DATA  │ UTC  1204        │
└─────────────────────────────┴──────────────────────────┴──────────────────┘
```

```
                         9/37                              10/37
DATE   UTC   ZONE   OCC              DATE   UTC   ZONE   OCC
FEB07  1934  LAST LEG 1              FEB07  1934  LAST LEG 4
FLIGHT PHASE: 06                    FLIGHT PHASE: 06
SOURCE: FCMC2 CMP                   SOURCE: FCMC2 CMP
REFUEL AUX VALVE(5210U)             FCMC2(SOM2)


FAILED SHUT                         CP ARINC RX17 MSNG LABEL
2130 0000 0000 0000 0002            9010 0000 0000 0000 390F
0000 0000 0000 0000 0000            0033 0006 0000 0000 1F00

                         11/37                             12/37
DATE   UTC   ZONE   OCC              DATE   UTC   ZONE   OCC
FEB08  0334  LAST LEG 3              FEB07  1934  LAST LEG 2
FLIGHT PHASE: 06                    FLIGHT PHASE: 06
SOURCE: FCMC2 CMP                   SOURCE: FCMC2 CMP
FUEL INR TK 4 TEMP SNSR             FUEL CTR TK R XFR PUMP
(11QR2)                             (6200L2)


ICP FDC2A RTD 6 FAIL                FAILED OFF
5530 0000 0000 0000 0003            4300 0000 0000 0000 0000
0000 0000 0000 0000 0000            0000 0000 0000 0000 0000

                         13/37                             14/37
DATE   UTC   ZONE   OCC              DATE   UTC   ZONE   OCC
FEB07  0534  PREV LEG 1             FEB07  0531  PREV LEG 3
FLIGHT PHASE: 06                    FLIGHT PHASE: 06
SOURCE: FCMC2 CMP                   SOURCE: FCMC2 CMP
POWER SUPPLY INTERRUPT              FCMC2(SOM2)


CP FCMS PSU INT > 220MS             ICP FDC2A RTD 6 FAIL
3080 0000 0000 0000 0000            7010 0000 0000 0000 0000
0000 0000 0000 0000 0000            0000 0000 0000 0000 0000

                         15/37                             16/37
DATE   UTC   ZONE   OCC              DATE   UTC   ZONE   OCC
FEB07  0530  PREV LEG 4             FEB06  1206  PREV LEG 4
FLIGHT PHASE: 06                    FLIGHT PHASE: 06
SOURCE: FCMC2 CMP                   SOURCE: FCMC2 CMP
FUEL INR TK 4 TEMP SNSR             FUEL INR TK 4 TEMP SNSR
(11QR2)                             (11QR2)


FOI TEMP AB COMPARE FAIL            FOI TEMP AB COMPARE FAIL
0530 0000 0000 0000 0000            0530 0000 0000 0000 0000
0000 0000 0000 0000 0000            0000 0000 0000 0000 0000
```

CONTINUED

```
A/C IDENT   G-VATL                                            CMC1 PRINTING
DATE        FEB07               MAINTENANCE
FLT NBR     VIR201          SYSTEM REPORT/TEST                 PAGE 03/05
FROM/TO     VHHH/EHAM            FCMC2                         DATE FEB28
START/END   1681/0413       TROUBLE SHOOTING DATA             UTC  1005
```

```
                  17/37                                       18/37
     DATE   UTC   ZONE   OCC              DATE   UTC   ZONE   OCC
     FEB05  2153  PREV LEG 1              FEB05  2149  PREV LEG 4
     FLIGHT PHASE: 02                     FLIGHT PHASE: 02
     SOURCE: FCMC2 CMP                    SOURCE: FCMC2 CMP
     FCMC2(5QM2)                          FUEL INR TK 4 TEMP SNSR
                                          (11QR2)

     FUEL TEMP IND FAIL                   FQI TEMP AB COMPARE FAIL
     3010 0000 0000 0000 0000             8530 0000 0000 0030 0000
     0000 0000 0000 0000 0000             0000 0000 0000 0000 0000

                  19/37                                       20/37
     DATE   UTC   ZONE   OCC              DATE   UTC   ZONE   OCC
     FEB04  0511  PREV LEG 3              FEB03  2017  PREV LEG 4
     FLIGHT PHASE: 02                     FLIGHT PHASE: 06
     SOURCE: FCMC2 CMP                    SOURCE: FCMC2 CMP
     FUEL INR TK 4 TEMP SNSR              FCMC1(5QM1)
     (11QR2)

     FQI TEMP AB COMPARE FAIL             MP ARINC RX13 MSNG LABEL
     6530 0000 0000 0000 0000             9020 0000 0000 0000 0200
     0000 0000 0000 0000 0000             0000 0000 0000 0000 0000

                  21/37                                       22/37
     DATE   UTC   ZONE   OCC              DATE   UTC   ZONE   OCC
     FEB03  2016  PREV LEG 4              FEB03  2016  PREV LEG 1
     FLIGHT PHASE: 06                     FLIGHT PHASE: 06
     SOURCE: FCMC2 CMP                    SOURCE: FCMC2 CMP
     FDC2(166QT2)                         POWER SUPPLY INTERRUPT

     CP ARINC RX12 MSNG LABEL             CP FCMS PSU INT > 220MS
     9040 0000 0000 0000 0015             3060 0000 0000 0000 0000
     0001 0006 0000 0000 0000             0000 0000 0000 0000 0000

                  23/37                                       24/37
     DATE   UTC   ZONE   OCC              DATE   UTC   ZONE   OCC
     FEB03  2015  PREV LEG 1              FEB03  0748  PREV LEG 3
     FLIGHT PHASE: 06                     FLIGHT PHASE: 06
     SOURCE: FCMC2 CMP                    SOURCE: FCMC2 CMP
     FCMC2(6QM2)                          FMGEC1+2(1CA1+1CA2)

     FUEL VALVE IND FAIL                  RTD DISAGREE
     3010 0000 0000 0000 0000             6FC0 0000 0000 0000 0000
     0000 0000 0000 0000 0000             0000 0000 0000 0000 0000
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┌─────────────────────────────────────────────────────────────────────────┐
│ A/C IDENT   G-VATL  │                              │  CMC1 PRINTING       │
│ DATE        FEB07   │         MAINTENANCE          │                      │
│ FLT NBR     VIR201  │      SYSTEM REPORT/TEST      │  PAGE 04/05          │
│ FROM/TO   VHHH/EHAM │           FCMC2              │  DATE FEB08          │
│ START/END  1621/0413│      TROUBLE SHOOTING DATA   │  UTC  1006           │
└─────────────────────────────────────────────────────────────────────────┘
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                          25/37                              26/37
IATE    UTC    ZONE    OCC          DATE    UTC    ZONE    OCC
'EB02   2245   PREV LEG 1           FEB02   2244   PREV LEG 1
'LIGHT PHASE: 06                    FLIGHT PHASE: 06
iOURCE: FCMC2 CMP                   SOURCE: FCMC2 CMP
'OWER SUPPLY INTERRUPT              FCMC2(50M2)


P FCMS PSU INT > 220MS              ICP FDC2A RTD 6 FAIL
1080 0000 0000 0000 0000            3010 0000 0000 0000 0000
1000 0000 0000 0000 0000            0000 0000 0000 0000 0000

                          27/37                              28/37
ATE    UTC    ZONE    OCC           DATE    UTC    ZONE    OCC
'EB02   2242   PREV LEG 4           FEB02   0620   PREV LEG 2
'LIGHT PHASE: 06                    FLIGHT PHASE: 06
OURCE: FCMC2 CMP                    SOURCE: FCMC2 CMP
UEL INR TK 4 TEMP SNSR              FUEL INR TK 4 TEMP SNSR
11QR2)                              (11QR2)

QI TEMP AB COMPARE FAIL             FQI TEMP AB COMPARE FAIL
1530 0000 0000 0000 0000            4530 0000 0000 0000 0000
1000 0000 0000 0000 0000            0000 0000 0000 0000 0000

                          29/37                              30/37
ATE    UTC    ZONE    OCC           DATE    UTC    ZONE    OCC
EB01    1611   PREV LEG 1           FEB01   1607   PREV LEG 3
LIGHT PHASE: 02                     FLIGHT PHASE: 02
OURCE: FCMC2 CMP                    SOURCE: FCMC2 CMP
CMC2(50M2)                          FUEL INR TK 4 TEMP SNSR
                                    (11QR2)

UEL TEMP IND FAIL                   FQI TEMP AB COMPARE FAIL
010 0000 0000 0000 0000             6530 0000 0000 0000 0000
000 0000 0000 0000 0000             0000 0000 0000 0000 0000

                          31/37                              32/37
ATE    UTC    ZONE    OCC           DATE    UTC    ZONE    OCC
AN31    1945   PREV LEG 4           JAN31   1204   PREV LEG 1
LIGHT PHASE: 06                     FLIGHT PHASE: 06
OURCE: FCMC2 CMP                    SOURCE: FCMC2 CMP
UEL INR TK 4 TEMP SNSR              REFUEL AUX VALVE(521QU)
11QR2)

QI TEMP AB COMPARE FAIL             FAILED OPEN
530 0000 0000 0000 0000             2130 0000 0000 0000 0000
000 0000 0000 0000 0000             0000 0000 0000 0000 0000
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                                CONTINUED

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┌─────────────────────────────────────────────────────────────────────────┐
│ A/C IDENT  .G-VATL │                          │ CMC1 PRINTING            │
│ DATE       FEB07   │      MAINTENANCE         │ PAGE 05/05               │
│ FLT NBR    VIR201  │    SYSTEM REPORT/TEST    │ DATE FEB08               │
│ FROM/TO    VHHH/EHAM│         FCMC2           │ UTC  1007                │
│ START/END  1621/0413│   TROUBLE SHOOTING DATA │                         │
└─────────────────────────────────────────────────────────────────────────┘
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                   33/37                                    34/37
DATE   UTC   ZONE   OCC                  DATE   UTC   ZONE   OCC
JAN31  0332  PREV LEG 4                  JAN30  1858  PREV LEG 1
FLIGHT PHASE: 06                         FLIGHT PHASE: 06
SOURCE: FCMC2 CMP                        SOURCE: FCMC2 CMP
FUEL INR TK 4 TEMP SNSR                  POWER SUPPLY INTERRUPT
(11QR2)

FQI TEMP AB COMPARE FAIL                 CP: FCMS PSU INT > 220MS
8530 0000 0000 0000 0000                 3080 0000 0000 0000 0000
0000 0000 0000 0000 0000                 0000 0000 0000 0000 0000

                   35/37                                    36/37
DATE   UTC   ZONE   OCC                  DATE   UTC   ZONE   OCC
JAN30  1852  PREV LEG 1                  JAN30  1401  PREV LEG 4
FLIGHT PHASE: 06                         FLIGHT PHASE: 06
SOURCE: FCMC2 CMP                        SOURCE: FCMC2 CMP
FCMC2(SQM2)                              FUEL INR TK 4 TEMP SNSR
                                         (11QR2)

FUEL TRANSFER MODE FAIL                  FQI TEMP AB COMPARE FAIL
3010 0000 0000 0000 0000                 8530 0000 0200 0000 0000
0000 0000 0000 0000 0000                 0000 0000 0000 0000 0000

                   37/37
DATE   UTC   ZONE   OCC
FEB07  1631  CLASS 3  3
FLIGHT PHASE: 06
SOURCE: FCMC2 CMP
FUEL INR TK 4 TEMP SNSR
(11QR2)

SENSOR B OPEN
5530 0000 0000 0000 0000
0000 0000 0000 0000 0000
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                         END OF REPORT
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DMC Troubleshooting Data Decode

Date and Time	DMC	Class	Message	
FEB07 16h55	1	3	Error code : 139 BITE message : FCMC2(5QM2)/DMC1(1WT1) ATA : 285134 Occurrences : 3 Event : 0 => No cockpit effect	Failure indice (Hexa) : 0 DMC : DMC 1 Failure status : Consolidated (At least 3 occurrences or > 10sec) Failure class : Class 3 Failure type : Externa
FEB08 03h30	1	1	Error code : 65 BITE message : POWER_SUP-PLY_INTERRUPT ATA : 240000 Occurrences : 1 Event : 2 => no communication from DMC to DMC subscribers (DUs,…)	Failure indice (Hexa) : D9 : short power cut DMC : DMC 1 Failure status : Confirmed Failure class : Class 1 Failure type : Internal
FEB07 16h55	2	3	Error code : 139 BITE message : FCMC2(5QM2)/DMC1(1WT1) ATA : 285134 Occurrences : 2 Event : 0 => No cockpit effect	Failure indice (Hexa) : 0 DMC : DMC2 Failure status : Consolidated (At least 3 occurrences or > 10sec) Failure class : Class 3 Failure type : External
FEB07 16h55	3	3	Error code : 139 BITE message : FCMC2(5QM2)/DMC3(1WT3) ATA : 285134 Occurrences : 2 Event : 0 => No cockpit effect	Failure indice (Hexa) : 0 DMC : DMC 3 Failure status : Consolidated (At least 3 occurrences or > 10sec) Failure class : Class 3 Failure type : External

Incident Flight Post-Flight Report

A/C IDENT .G-VATL DATE FEB07 FLT NBR VIR201 FROM/TO VHHH/EHAM START/END 1621/0413	MAINTENANCE PREVIOUS FLIGHT REPORT LEG 01 DB/N 565	CMC1 PRINTING PAGE 01/04 DATE FEB09 UTC 1819
18 COCKPIT EFFECTS	**UTC FLIGHT PHASE**	**22 FAULTS**
ATA 2851 FUEL FCMC 2 FAULT	1621 Climb 05	ATA 284915 Source FCMC2 Class 1 Identifiers Hard FCMC1 FUEL INR TK 4 TEMP SNSR (110R2)
ATA 3130 AINTENANCE STATUS DAR	1621 Takeoff Roll 04	ATA 313652 Source *ACMS Class 2 Hard DAR MEDIA LOW(2TV)
ATA 3600 MAINTENANCE STATUS BMC 1-1	1621 Takeoff Roll 04	ATA 362217 Source *BMC1-1 Class 2 Hard APU1 LOOP A
ATA 3831 MAINTENANCE STATUS TOILET	1621 Takeoff Roll 04	ATA 383115 Source *VSC Class 2 Hard APS XMTR RH2 (32MG)
	1621 Climb 05	ATA 256200 Source CIDS1 Class 1 Hard SLIDE BTL 1L/ DEU B (300RH1)
	1621 Climb 05	ATA 253453 Source *VC Class 2 Hard RC(3741ML)
	1622 Climb 05	ATA 304611 Source CIDS1 Class 1 Hard HEATR 302/ IPCU FWD(140S)
	1622 Cruise 06	ATA 216334 Source FWS Class 1 Hard ZC(630HK)
CONTINUED		

A/C IDENT .G-VATL DATE FEB07 FLT NBR VIR201 FROM/TO VHHH/EHAM START/END 1621/0413	MAINTENANCE PREVIOUS FLIGHT REPORT LEG 01 DB/N 565	CMC1 PRINTING PAGE 02/04 DATE FEB09 UTC 1819
18 COCKPIT EFFECTS	UTC FLIGHT PHASE	22 FAULTS
ATA 2851 FUEL FDC 2 FAULT	1626 Cruise 06	ATA 284235 Source FCMC2 Class 1 Identifiers Hard FCMC1 FDC2(166QT2)
	1655 Cruise 06	ATA 240000 Source FCMC2 Class 1 Identifiers Intermittent FWS POWER SUPPLY INTERRUPT
	1714 Cruise 06	ATA 304611 Source CIDS1 Class 1 Hard HEATR 304/ IPCU FWD(14DS)
ATA 2851 MAINTENANCE STATUS FCMC 1	1934 Cruise 06	
	1934 Cruise 06	ATA 282753 Source *FCMC1 Class 1 Hard FUEL TRIM TK ISOL VALVE (7020N)
	1948 Cruise 06	ATA 454122 Source AFS Class 1 Hard PRINTER(2TP)
	2233 Cruise 06	ATA 313652 Source *ACMS Class 2 Hard DAR(2TV)
	0151 Cruise 06	ATA 237552 Source TACS Class 1 Hard CAMERA2(7RM)/CIU(1RM)
CONTINUED		

A/C IDENT .G-VATL DATE FEB07 FLT NBR VIR201 FROM/TO VHHH/EHAM START/END 1621/0413	MAINTENANCE PREVIOUS FLIGHT REPORT LEG 01 DB/N 565	CMC1 PRINTING PAGE 03/04 DATE FEB09 UTC 1820
18 COCKPIT EFFECTS	**UTC FLIGHT PHASE**	**22 FAULTS**
ATA 7321 MAINTENANCE STATUS EEC 1B	0329 Cruise 06	
ATA 2420 "LEC GEN 1 FAULT	0330 Cruise 06	ATA 240000 Source DMC1 Class 1 Identifiers Intermittent SFCC-S1 SFCC-F1 POWER SUPPLY INTERRUPT
ATA 3021 A.ICE ENG 1 VALVE OPEN	0330 Cruise 06	
ATA 7100 ENG 1 FAIL	0330 Cruise 06	
ATA 7321 'AINTENANCE STATUS ːEC 1A	0330 Cruise 06	ATA 731241 Source *EEC1A Class 2 Identifiers Hard *EEC1B FUEL PUMP (E1-5050EB)/ FUEL LP SW (E1-4075KS)
ATA 7321 ENG 1 LP SHAFT PROT LOSS	0331 Cruise 06	ATA 732152 Source EEC1B Class 1 Identifiers Hard DMC3 EEC1A HMU (E1-4000KC) SOV POS
ATA 7100 ENG 1 SHUT DOWN	0331 Cruise 06	
	0331 Cruise 06	ATA 291151 Source HSMU Class 1 Hard G ENG1 PMP (E1-4000JG)/ G HYD RSVR
CONTINUED		

A/C IDENT .G-VATL DATE FEB07 FLT NBR VIR201 FROM/TO VHHH/EHAM START/END 1621/0413	MAINTENANCE PREVIOUS FLIGHT REPORT LEG 01 DB/N 565	CMC1 PRINTING PAGE 04/04 DATE FEB09 UTC 1820
18 COCKPIT EFFECTS	**UTC FLIGHT PHASE**	**22 FAULTS**
ATA 7310 Not Displayed ENG 1 HP FUEL VALVE	0333 Cruise 06	ATA 732134 Source EEC1A Class 1 Hard EEC (E1-4000KS)
ATA 7321 AINTENANCE STATUS EEC 4A	0341 Cruise 06	ATA 731241 Source *EEC4B Class 2 Identifiers Hard *EEC4A FUEL PUMP (E4-5050EB)/ FUEL LP SU (E4-4075KS)
ATA 7321 MAINTENANCE STATUS EEC 4B	0341 Cruise 06	
ATA 7325 ENG 1 MINOR FAULT	0345 Cruise 06	ATA 732152 Source EEC1A Class 1 Hard HMU (E1-4000KC) AUTOSTART SOV TM A
ATA 8000 NG 1 START FAULT	0346 Cruise 06	

Previous Flight Post-Flight Report

A/C IDENT .G-VATL DATE FEB07 FLT NBR VIR201 FROM/TO YSSY/VHHH START/END 0455/1330	MAINTENANCE PREVIOUS FLIGHT REPORT LEG 02 DB/N 565	CMC1 PRINTING PAGE 01/02 DATE FEB09 UTC 1817
07 COCKPIT EFFECTS	**UTC FLIGHT PHASE**	**14 FAULTS**
ATA 3600 MAINTENANCE STATUS BMC 1-1	0456 Engine Start 02	ATA 362216 Source *BMC2-3 Class 2 Identifiers Hard *BMC1-1 PACK2 LOOP A
ATA 3600 MAINTENANCE STATUS BMC 2-3	0456 Engine Start 02	
	0456 Engine Start 02	ATA 253453 Source *VC Class 2 Hard RC(3792ML)
	0456 Engine Start 02	ATA 304611 Source CIDS1 Class 1 Hard HEATR 302/ IPCU FWD(14DS)
	0457 Engine Start 02	ATA 216334 Source FWS Class 1 Hard ZC(630HK)
	0530 Cruise 06	ATA 284915 Source FCMC2 Class 1 Identifiers Hard FCMC1 FUEL INR TK 4 TEMP SNSR (110R2)
ATA 2851 FUEL FCMC 2 FAULT	0531 Cruise 06	ATA 285134 Source FCMC2 Class 1 Hard FCMC2(5QM2)
	0534 Cruise 06	ATA 240000 Source FCMC2 Class 1 Identifiers Intermittent FWS POWER SUPPLY INTERRUPT
CONTINUED		

A/C IDENT .G-VATL DATE FEB07 FLT NBR VIR201 FROM/TO YSSY/VHHH START/END 0455/1330	MAINTENANCE PREVIOUS FLIGHT REPORT LEG 02 DB/N 565	CMC1 PRINTING PAGE 02/02 DATE FEB09 UTC 1818
07 COCKPIT EFFECTS	**UTC FLIGHT PHASE**	**14 FAULTS**
	0554 Cruise 06	ATA 304611 Source CIDS1 Class 1 Hard HEATR 304/ IPCU FWD(14DS)
ATA 2851 FUEL FCMC 1+2 FAULT	0604 Cruise 06	ATA 285134 Source FCMC1 Class 1 Hard FCMC1(50M1)
ATA 2827 FUEL T TK PMPS FAULT	0604 Cruise 06	
ATA 2827 FUEL T TK XFR FAULT	0610 Cruise 06	ATA 240000 Source FCMC1 Class 1 Identifiers Intermittent DMC3 FUS POWER SUPPLY INTERRUPT
	0850 Cruise 06	ATA 253453 Source *VC Class 2 Hard RC(3741ML)
	0933 Cruise 06	ATA 383141 Source VSC Class 1 Hard MD LAV 54
ATA 3130 MAINTENANCE STATUS DAR	1200 Cruise 06	ATA 313652 Source *ACMS Class 2 Hard DAR MEDIA LOW(2TV)
	1328 Rollout 08	ATA 256200 Source CIDS1 Class 1 Hard SLIDE 8TL 3L/ DEU B (300RH5)
END OF REPORT		

Time Line

Date	UTC	Event	Source	Notes
07/02/2005	04:49:00	off blocks at Sydney	tech log 1201302	
07/02/2005	04:55:00	PFR reports start of VSSY - VHHH sector	PFR (SYD-HKG)	
07/02/2005	05:04:00	take off from Sydney	tech log 1201302	
07/02/2005	05:30:00	FCMC 2 CMP fails FUEL INR TK 4 TEMP SNSR due FQI TEMP RB COMPARE FAIL	TSD FCMC 2 24/98 and TSD FCMC 2 A/C 15/37	
07/02/2005	05:30:00	FCMC 1 CMP fails FUEL INR TK 4 TEMP SNSR due FQI TEMP RB COMPARE FAIL	TSD FCMC 1 15/37 and TSD FCMC 1 A/C 11/34	
07/02/2005	05:30:00	PFR reports FAULTS : ATA 284915, SOURCE : FCMC2, IDENTIFIERS FCMC 1, CLASS 1, HARD, FUEL INR TK 4 TEMP SNSR	PFR (SYD-HKG)	
07/02/2005	05:31:00	FCMC 2 CMP fails FCMC2 due ICP FDC2A RTD 6 FAIL	TSD FCMC 2 33/98 and TSD FCMC 2 A/C 14/37	
07/02/2005	05:31:00	PFR reports FAULTS : ATA 285134, SOURCE : FCMC2, CLASS 1, HARD, FCMC2	PFR (SYD-HKG)	
07/02/2005	05:31:00	PFR reports COCKPIT EFFECT : ATA 2851 FUEL FCMC 2 FAULT	PFR (SYD-HKG)	
07/02/2005	05:34:00	FCMC 2 CMP fails POWER SUPPLY INTERRUPT due CP FCMS PSU INT >225MS	TSD FCMC 2 22/98 and TSD FCMC 2 A/C 13/37	
07/02/2005	05:34:00	PFR reports FAULTS : ATA 240000, SOURCE : FCMC2, IDENTIFIERS FWS, CLASS 1, INTERMITTANT, POWER SUPPLY INTERRUPT	PFR (SYD-HKG)	Reset of FCMC 2, Unsuccessful due later FCMC 1+2 FAULT
07/02/2005	05:34:00	FWC1 fails FCMC2 due No Refresh Arinc Bus as External Failure soc 4	TSD FWC 1	
07/02/2005	05:34:00	FWC2 fails FCMC2 due No Refresh Arinc Bus as External Failure soc 4	TSD FWC 2	
07/02/2005	06:03:30	TSD DMC 1 Error code : 139 BITE message : FCMC2(SGN2)DMC1(1WT1) ATA : 285134 Occurrences : 4 Event : 0 => No cockpit effect	TSD DMC 1	
07/02/2005	06:03:30	TSD DMC 2 Error code : 139 BITE message : FCMC2(SGN2)DMC1(1WT1) ATA : 285134 Occurrences : 4 Event : 0 => No cockpit effect	TSD DMC 2	
07/02/2005	06:03:30	TSD DMC 3 Error code : 139 BITE message : FCMC2(SGN2)DMC3(1WT2) ATA : 285134 Occurrences : 3 Event : 0 => No cockpit effect	TSD DMC 3	
07/02/2005	06:04:00	FCMC 1 CMP fails FCMC 1 due ICP FDC2A RTD 6 FAIL	TSD FCMC 1 14/37 and TSD FCMC 1 A/C 10/34	
07/02/2005	06:04:00	PFR reports COCKPIT EFFECT : ATA 2851 FUEL FCMC 1+2 FAULT	PFR (SYD-HKG)	
07/02/2005	06:04:00	PFR reports FAULTS : ATA 285134, SOURCE : FCMC1, CLASS 1, HARD, FCMC1	PFR (SYD-HKG)	
07/02/2005	06:04:00	PFR reports COCKPIT EFFECT : ATA 2827 FUEL T TK PUMPS FAULT	PFR (SYD-HKG)	
07/02/2005	06:10:00	FCMC 1 CMP fails POWER SUPPLY INTERRUPT due CP FCMS PSU INT > 220MS	TSD FCMC 1 13/37 and TSD FCMC 1 A/C 9/34	
07/02/2005	06:10:00	PFR reports COCKPIT EFFECT : ATA 2827 FUEL T TK XFR FAULT	PFR (SYD-HKG)	
07/02/2005	06:10:00	PFR reports FAULTS : ATA 240000, SOURCE : FCMC2, IDENTIFIERS DMC3 FWS, CLASS 1, INTERMITTANT, POWER SUPPLY INTERRUPT	PFR (SYD-HKG)	Reset of FCMC 1 and not FCMC 2
07/02/2005	06:10:00	FWC1 fails FCMCA due No Refresh Arinc Bus as External Failure soc 1	TSD FWC 1	
07/02/2005	06:10:00	FWC2 fails FCMCA due No Refresh Arinc Bus as External Failure soc 1	TSD FWC 2	
07/02/2005	06:10:30	TSD DMC 1 Error code : 139 BITE message : FCMC1(SGN1)DMC2(1WT2) ATA : 285134 Occurrences : 1 Event : 0 => No cockpit effect	TSD DMC 1	
07/02/2005	06:10:30	TSD DMC 2 Error code : 139 BITE message : FCMC1(SGN1)DMC2(1WT2) ATA : 285134 Occurrences : 1 Event : 0 => No cockpit effect	TSD DMC 2	
07/02/2005	06:10:30	TSD DMC 3 Error code : 139 BITE message : FCMC2(SGN2)DMC3(1WT2) ATA : 285134 Occurrences : 1 Event : 5 => Part of image flagged (A429 bus failure)	TSD DMC 3	
07/02/2005	06:10:30	TSD DMC 3 Error code : 139 BITE message : FCMC1(SGN1)DMC3(1WT2) ATA : 285134 Occurrences : 1 Event : 5 => Part of image flagged (A429 bus failure)	TSD DMC 3	
07/02/2005	13:26:00	Landing at Hong Kong	tech log 1201302	
07/02/2005	13:30:00	PFR reports end of VSSV - VHHH sector	PFR (SYD-HKG)	
07/02/2005	13:32:00	on blocks at Hong Kong	tech log 1201302	
07/02/2005	13:45:00			
07/02/2005	14:00:00	Fuel T TK pumps fault, simulatenous with FCMC 1+2 fault, after dual reset pumps restored. FCMC 1 and 2 test OK. Trim pumps checked.	tech log 1201302	
07/02/2005	14:00:00	Fuel T TK XFR FAULT, ECAM actions carried out. Caused by trim tank pumps fault see item 1.	tech log 1201302	
07/02/2005	15:00:00	Refuel of aircraft. Pre refuel 12200, Uplift 124387, Depart 136200	Tech log 1201360	
07/02/2005	15:30:00	FCMC 2 Fault - Reset.	crew interview	
07/02/2005	15:30:00	FCMC 1 Fault - Reset.	crew interview	
07/02/2005	15:56:00	off blocks at Hong Kong	tech log report 1201304	
07/02/2005	16:15:00	FCMC 1 FAULT flicker on FDR for 1 sec or so?	FDR	
07/02/2005	15:58:00	Flicker of FCMC fault, unknown which one (but 2 mentioned).	crew interview	Will not appear on CMC or PFR as fault was less than 5 secs
07/02/2005	16:21:00	PFR reports start of VHHH - EGLL DIVERT EHAM sector	PFR (HKG-AWS)	
07/02/2005	16:21:00	take off from Hong Kong	tech log report 1201304	
07/02/2005	16:21:00	PFR reports COCKPIT EFFECT : ATA 2851 FUEL FCMC 2 FAULT	PFR (HKG-AWS)	Fault would be inhibited until 1500 feet in climb.
07/02/2005	16:21:00	PFR reports FAULTS : ATA 284915, SOURCE : FCMC2, IDENTIFIERS FCMC 1, CLASS 1, HARD, FUEL INR TK 4 TEMP SNSR	PFR (HKG-AWS)	TSD of FCMC 1 and FCMC 2 should have recorded the faults sent to the CMC to produce this line on the PFR. The PFR will only show the cockpit effect once and records when it was first shown.
07/02/2005	16:21:00	FCMC 1 CMP fails FUEL INR 1 TK F7M DENS due FQI DENSITY OUT OF RANGE - CLASS 3	TSD FCMC 1 A/C 34/84	
07/02/2005	16:21:45	centre Tank stops transfer, as inner 4 went above 19200 Kg.	FDR	trim = 5080, Left Outer = 4441, Right Outer = 4393, Center = 34458, 1 inner = 17503, 2 inner = 20836, 3 inner = 25720, 4 inner = 17969, total = 136453
07/02/2005	16:26:00	PFR reports COCKPIT EFFECT : ATA 2851 FUEL FDC 2 FAULT	PFR (HKG-AWS)	TSD of FCMC 1 and FCMC 2 should have recorded the faults sent to the CMC to produce this line on the PFR. The PFR will only show the cockpit effect once and records when it was first shown.
07/02/2005	16:26:00	PFR reports FAULTS : ATA 284235, SOURCE : FCMC2, IDENTIFIERS FCMC 1, CLASS 1, HARD, FDC2	PFR (HKG-AWS)	
07/02/2005	16:26:00	ECAM Fuel Page displayed 2 seconds or less.		ECAM DISPLAY MODE - WARNING.
07/02/2005	16:31:00	FCMC 1 CMP fails FUEL INR TK 4 TEMP SNSR due SENSOR B OPEN - CLASS 3	TSD FCMC 1 A/C 33/34	
07/02/2005	16:31:00	FCMC 2 CMP fails FUEL INR TK 4 TEMP SNSR due SENSOR B OPEN - CLASS 3	TSD FCMC 2 A/C 37/37	
07/02/2005	16:41:00	FL205	FDR	trim = 5109, Left Outer = 4470, Right Outer = 4354, Center = 28362, 1 inner = 17911, 2 inner = 24929, 3 inner = 24997, 4 inner = 17793
07/02/2005	16:41:00	Trim tank contents starts to increase	FDR	
07/02/2005	16:45:00	Trim Tank contents stabilise	FDR	
07/02/2005	16:49:00	FL286	FDR	trim = 6273, Left Outer = 4470, Right Outer = 4354, Center = 25575, 1 inner = 18085, 2 inner = 24878, 3 inner = 24994, 4 inner = 17911
07/02/2005	16:55:00	PFR reports FAULTS : ATA 240000, SOURCE : FCMC2, IDENTIFIERS FWS, CLASS 1, INTERMITTANT, POWER SUPPLY INTERRUPT	PFR (HKG-AWS)	FCMC 2 RESET, unsuccessful by tech log and crew interview. Fault sent to CMC by FCMC should have been recorded in TSD of the computer.
07/02/2005	16:55:00	ECAM Fuel Page ON. 33,500 ft	FDR	trim = 6269, Left Outer = 4470, Right Outer = 4354, Center = 23556, 1 inner = 17737, 2 inner = 25459, 3 inner = 25684, 4 inner = 17853, total = 174332. ECAM DISPLAY MODE - WARNING.
07/02/2005	16:55:00	FWC1 fails FCMC2 due No Refresh Arinc Bus as External Failure soc 2	TSD FWC 1	due to FCMC 2 reset, but two occurrences indicate a later failure of the ARINC bus.
07/02/2005	16:55:00	FWC2 fails FCMC2 due No Refresh Arinc Bus as External Failure soc 2	TSD FWC 2	due to FCMC 2 reset, but two occurrences indicate a later failure of the ARINC bus.
07/02/2005	16:55:30	TSD DMC 1 Error code : 139 BITE message : FCMC2(SGN2)DMC1(1WT1) ATA : 285134 Occurrences : 3 Event : 0 => No cockpit effect	TSD DMC 1	

Date	UTC	Event	Source	Notes
07/02/2005	16:55:00	TSD DMC 2 Error code : 139 BITE message : FCMC2(SQM2)DMC1(1WT1) ATA : 285134 Occurrences : 2 Event : 0 => No cockpit effect	TSD DMC 2	
07/02/2005	16:55:00	TSD DMC 3 Error code : 139 BITE message : FCMC2(SQM2)DMC3(1WT3) ATA : 285134 Occurrences : 2 Event : 0 => No cockpit effect	TSD DMC 3	
07/02/2005	15:55:41	Master Caution	FDR	
07/02/2005	15:55:41	ECAM Cruise Page Displayed	FDR	
07/02/2005	15:58:13	ECAM Fuel Page ON	FDR	ECAM DISPLAY MODE - WARNING
07/02/2005	15:58:13	ECAM Status Page ON	FDR	
07/02/2005	15:59:13	ECAM Cruise Page ON	FDR	
07/02/2005	16:59:37	ECAM Secondary Engine Page ON	FDR	
07/02/2005	16:59:41	ECAM multiple pages selected	FDR	
07/02/2005	17:00:00	ECAM Cruise page ON	FDR	
07/02/2005	18:50:00	ECAM Fuel Page ON (4 seconds or less !) Followed by manual multiple pages before return to Cruise Page.	FDR	ECAM DISPLAY MODE - WARNING
07/02/2005	19:04:09	ECAM Fuel Page ON 32 seconds	FDR	ECAM DISPLAY MODE - WARNING
07/02/2005	19:28:06	Centre Tank stops transfer, as inner 4 vent above 18350 Kg.	FDR	trim = 6241, Left Outer = 4412 Right Outer = 4209, Center = 5312 1 inner = 17795 2 inner = 20669 3 inner = 20146 4 inner = 18305 total = 96376
07/02/2005	19:34:00	PFR reports COCKPIT EFFECT : ATA 2851 MAINTENANCE STATUS FCMC 1	PFR (HKG-AMS)	no related faults on PFR as CMC is overwhelmed by faults (it has a 6 fault buffer).
07/02/2005	19:34:00	PFR reports FAULTS : ATA 282753, SOURCE *FCMC1, CLASS 1, HARD, FUEL TRIM TK ISOL VALVE	PFR (HKG-AMS)	* against source means a class 2 fault has been detected by FCMC1 but not shown on the PFR
07/02/2005	19:34:00	FCMC 1 CMP fails FCMC 2 due FCMC ALT HEALTH MISMATCH	TSD FCMC 1 827 and TSD FCMC 1 A/C 404	earlier TSD faults for FCMC1 were not evident before this point due to the 8 fault storage limit and the over writing of the earliest fault
07/02/2005	19:34:00	FCMC 2 CMP fails FCMC3 due CP ARINC R317 MISSING LABEL (INFUSP A.FAULT)	TSD FCMC 2 1908 and TSD FCMC 2 A/C 1007	earlier TSD faults for FCMC2 were not evident before this point due to the 8 fault storage limit and the over writing of the earliest fault
07/02/2005	19:34:00	FCMC 1 CMP fails FUEL CTR TK L XFR PUMP due FAILED OFF	TSD FCMC 1 1007 and TSD FCMC 1 A/C 604	
07/02/2005	19:34:00	FCMC 1 CMP fails FUEL CTR TK R XFR PUMP due FAILED OFF	TSD FCMC 1 807 and TSD FCMC 1 A/C 504	
07/02/2005	19:34:00	FCMC 2 CMP fails FUEL CTR TK R XFR PUMP due FAILED OFF	TSD FCMC 2 2108 and TSD FCMC 2 1207	
07/02/2005	19:34:00	FCMC 2 CMP fails REFUEL AUX VALVE due FAILED SHUT	TSD FCMC 2 1908 and TSD FCMC 2 A/C 907	due to attempted workround by FCMC as a result of ctr tk transfer pumps reported failed
07/02/2005	19:34:00	FCMC 1 CMP fails REFUEL AUX VALVE due FAILED SHUT	TSD FCMC 1 707 and TSD FCMC 1 A/C 304	due to attempted workround by FCMC as a result of ctr tk transfer pumps reported failed
07/02/2005	19:34:01		FDR	trim = 6241, Left Outer = 4412, Right Outer = 4209, Center = 5312, 1 inner = 17650, 2 inner = 20466, 3 inner = 19043, 4 inner = 18143, total = 96376
07/02/2005	19:41:00	1 inner drops below 17200	FDR	trim = 6241, Left Outer = 4412, Right Outer = 4209, Center = 5312, 1 inner = 17185, 2 inner = 20233, 3 inner = 19095, 4 inner = 17679, total = 94966
07/02/2005	19:41:00	ECAM Cruise Page ON	FDR	
07/02/2005	19:41:00	NO Caution or Warning	FDR	
07/02/2005	19:41:00	FCMC 2 CMP fails FUEL INR TK 1 XFR VALVE due FAILED SHUT	TSD FCMC 2 1708 and and TSD FCMC 2 A/C 807	due to fuel transfer attempted from centre to inner tank 1
07/02/2005	19:58:49	4 inner drops below 17200	FDR	trim = 6241, Left Outer = 4412, Right Outer = 4209, Center = 5312, 1 inner = 16105, 2 inner = 19505, 3 inner = 18006, 4 inner = 17158, total = 91966
07/02/2005	19:58:49	ECAM Cruise Page ON	FDR	
07/02/2005	20:40:32	3 inner drops below 17700	FDR	trim = 6241, Left Outer = 4412, Right Outer = 4209, Center = 5312, 1 inner = 16805, 2 inner = 17682, 3 inner = 17145, 4 inner = 15296
07/02/2005	20:46:44	NO ECAM	FDR	trim = 6241, Left Outer = 4412, Right Outer = 4209, Center = 5312, 1 inner = 16431, 2 inner = 17650, 3 inner = 16963, 4 inner = 15982. ECAM DISPLAY MODE - WARNING FOR 1 SEC
07/02/2005	20:57:49	2 inner drops below 17200	FDR	trim = 6241, Left Outer = 4412, Right Outer = 4209, Center = 5312, 1 inner = 14195, 2 inner = 17165, 3 inner = 16480, 4 inner = 14779
07/02/2005	21:04:00	ECAM Secondary Engine Page ON	FDR	ECAM DISPLAY MODE - MANUAL
07/02/2005	21:04:00	then cycles through pages	FDR	
07/02/2005	21:05:17	ECAM Fuel Page ON	FDR	ECAM DISPLAY MODE - MANUAL
07/02/2005	21:05:33	ECAM Cruise Page ON	FDR	
07/02/2005	21:05:45	ECAM Fuel Page ON	FDR	
07/02/2005	21:05:49	ECAM Cruise Page ON	FDR	
07/02/2005	21:07:25	ECAM Status Page ON	FDR	ECAM DISPLAY MODE - WARNING FOR 1 SEC
07/02/2005	21:07:41	ECAM Fuel Page ON	FDR	ECAM DISPLAY MODE - MANUAL
07/02/2005	21:07:57	ECAM Cruise Page ON	FDR	
07/02/2005	21:14:00	Both 1 and 4 inner below 14000	FDR	trim = 6212, Left Outer = 4412, Right Outer = 4209, Center = 5312, 1 inner = 13704, 2 inner = 16518, 3 inner = 16062, 4 inner = 13992. Expected FUEL CTR/INR TXF FAULT
07/02/2005	22:29:00	ECAM Fuel Page ON	FDR	ECAM DISPLAY MODE - MANUAL
07/02/2005	22:29:13	ECAM Cruise Page ON	FDR	
07/02/2005	22:58:37	ECAM Status page	FDR	ECAM DISPLAY MODE - WARNING
07/02/2005	22:59:03	ECAM Multiple pages cycled	FDR	ECAM DISPLAY MODE - MANUAL
07/02/2005	22:59:15	ECAM Cruise Page ON	FDR	
07/02/2005	23:58:25	ECAM Fuel Page ON then Cruise page then Fuel Page then back to Cruise	FDR	ECAM DISPLAY MODE - WARNING FOR 1 SEC
08/02/2005	00:03:00	ECAM Status page. 4 seconds or less !	FDR	FLIGHT PHASE ?
08/02/2005	00:30:00	ECAM Multiple pages cycled	FDR	ECAM DISPLAY MODE - MANUAL
08/02/2005	01:28:53	1 inner drops below 4000	FDR	trim = 6241, Left Outer = 4383, Right Outer = 4209, Center = 5312, 1 inner = 3948, 2 inner = 7257, 3 inner = 6753, 4 inner = 6470, total = 42583. Expected FUEL TRIM TK TXFR FAULT
08/02/2005	01:37:53	No ECAM	FDR	ECAM DISPLAY MODE - WARNING FOR 1 SEC
08/02/2005	01:44:41	4 inner drops below 4000	FDR	trim = 6241, Left Outer = 4383, Right Outer = 4209, Center = 5312, 1 inner = 3396, 2 inner = 6734, 3 inner = 6270, 4 inner = 3948, total = 40493
08/02/2005	02:28:00	FCMC 1 CMP fails FUEL R OUT TK INLET VLV due FAILED SHUT	TSD FCMC 1 1107 and TSD FCMC 1 A/C 704	due to fuel transfer attempted from outer to inner tanks
08/02/2005	02:28:00	FCMC 1 CMP fails FUEL L OUT TK INLET VLV due FAILED SHUT	TSD FCMC 1 1207 and TSD FCMC 1 A/C 804	due to fuel transfer attempted from outer to inner tanks
08/02/2005	02:28:13	1 inner drops below 2000	FDR	trim = 6241, Left Outer = 4383, Right Outer = 4209, Center = 5312, 1 inner = 1974, 2 inner = 5312, 3 inner = 4877, 4 inner = 2467, total = 36775. Expected FUEL OUTR TK TXFR FAULT
08/02/2005	02:44:17	4 inner drops below 2000	FDR	trim = 6241, Left Outer = 4383, Right Outer = 4209, Center = 5312, 1 inner = 1422, 2 inner = 4059, 3 inner = 4393, 4 inner = 1940, total = 32713
08/02/2005	02:58:21	1 inner < 1000	FDR	trim = 6241, Left Outer = 4383, Right Outer = 4209, Center = 5312, 1 inner = 987, 2 inner = 4354, 3 inner = 4040, 4 inner = 1460. Expected FUEL LO LVL INR 1
08/02/2005	03:02:37	ECAM Fuel Page ON then back to Cruise page 4 seconds or less	FDR	ECAM DISPLAY MODE - MANUAL
08/02/2005	03:28:57	1 inner reads zero	FDR	trim = 6241, Left Outer = 4383, Right Outer = 4209, Center = 5312, 1 inner = 0, 2 inner = 3362, 3 inner = 2961, 4 inner = 522, total = 26995
08/02/2005	03:29:00	PFR reports COCKPIT EFFECT : ATA 7321 MAINTENANCE STATUS EEC1B	PFR (HKG-AMS)	Start of engine run down
08/02/2005	03:29:37	Engine 1 starts to spool down	FDR	
08/02/2005	03:29:53	ECAM Secondary Engine Page ON	FDR	ECAM DISPLAY MODE - MANUAL
08/02/2005	03:29:57	ECAM Cruise Page ON	FDR	
08/02/2005	03:30:00	PFR reports COCKPIT EFFECT : ATA 2420 ELEC GEN 1 FAULT	PFR (HKG-AMS)	
08/02/2005	03:30:00	PFR reports COCKPIT EFFECT : ATA 3021 A ICE ENG 1 VALVE OPEN	PFR (HKG-AMS)	
08/02/2005	03:30:00	PFR reports COCKPIT EFFECT : ATA 7100 ENG 1 FAIL	PFR (HKG-AMS)	
08/02/2005	03:30:00	PFR reports COCKPIT EFFECT : MAINTENANCE STATUS EEC 1A	PFR (HKG-AMS)	
08/02/2005	03:30:00	PFR reports FAULTS : ATA 240980, SOURCE SMC1, IDENTIFIERS SFCC-S1 SFCC-F1, CLASS 1, INTERMITTANT, POWER SUPPLY INTERRUPT	PFR (HKG-AMS)	
08/02/2005	03:30:00	PFR reports FAULTS : ATA 731241, SOURCE *EEC1A, IDENTIFIERS 'EEC1B, CLASS 2, HARD, FUEL PUMP, FUEL PUMP LP SW	PFR (HKG-AMS)	
08/02/2005	03:30:00	TSD DMC 1 Error code : 65 BITE message : POWER_SUPPLY_INTERRUPT ATA : 240000 Occurrences : 1 Event : 2 => no communication from DMC to DMC subscribers (DUs,...)	TSD DMC 1	
08/02/2005	03:30:45	Master CAUTION	FDR	
08/02/2005	03:30:45	ECAM Elec AC Page ON	FDR	
08/02/2005	03:30:45	Engine 1 Master OF	FDR	
08/02/2005	03:30:53	Master CAUTION	FDR	
08/02/2005	03:30:53	ECAM Secondary Engine Page ON	FDR	

Date	UTC	Event	Source	Notes
06/02/2005	03:31:00	PFR reports COCKPIT EFFECT : ATA 7321 ENG 1 LP SHAFT PROT LOSS	PFR (HKG-AMS)	
06/02/2005	03:31:00	PFR reports COCKPIT EFFECT : ATA 7100 ENG 1 SHUT DOWN	PFR (HKG-AMS)	
06/02/2005	03:31:00	PFR reports FAULTS : ATA 732152, SOURCE EEC1s, IDENTIFIERS DMC3 EEC1A, CLASS 1, HARD, HMU, SOV POS	PFR (HKG-AMS)	
06/02/2005	03:31:00	PFR reports FAULTS : ATA 291151, SOURCE HSMU, CLASS 1, HARD, G ENG 1 PNP, G HYD RES	PFR (HKG-AMS)	
06/02/2005	03:31:09	TSD DMC 3 Error code : 25 BITE message : EEC(E1-4000KS) ATA : 732134 Occurrences : 2 Event : 5 => Fast of image flagged (A429 bus failure)	TSD DMC 3	
06/02/2005	03:32:46	ECAM Cruise Page ON	FDR	Flight phase dependent
06/02/2005	03:33:00	PFR reports COCKPIT EFFECT : ATA 7310 not displayed ENG 1 HP FUEL VALVE	PFR (HKG-AMS)	
06/02/2005	03:33:00	PFR reports FAULTS : ATA 732134, SOURCE EEC1A, CLASS 1, HARD, EEC	PFR (HKG-AMS)	
06/02/2005	03:33:13	ECAM cycled through multiple pages	FDR	ECAM DISPLAY MODE - WARNING
06/02/2005	03:34:00	FCMC 2 CMP fails FUEL, INR TK 4 TEMP SNSR due ICP FDC2A RTD 6 FAIL	TSD FCMC 2 29/08 and and TSD FCMC 2 A/C 11/37	
09/03/2005	03:35:15	"… and fcmc two that we had originally "	CVR	
06/02/2005	03:36:33	ECAM Fuel Page ON	FDR	ECAM DISPLAY MODE - MANUAL
09/03/2005	03:35:50	"why has that gone to zero "	CVR	
09/03/2005	03:36:38	"i don't think that was a wind down because of fuel starvati	CVR	
06/02/2005	03:40:41	4 inner reads zero	FDR	trim = 6241, Left Outer = 4383, Right Outer = 4329, Center = 5312, 1 inner = 0, 2 inner = 2844, 3 inner = 2467, 4 inner = 0, total = 25456
06/02/2005	03:41:00	PFR reports COCKPIT EFFECT : ATA 7321 MAINTENANCE STATUS EEC4A	PFR (HKG-AMS)	Engine 4 starts run down
06/02/2005	03:41:00	PFR reports COCKPIT EFFECT : ATA 7321 MAINTENANCE STATUS EEC4B	PFR (HKG-AMS)	
06/02/2005	03:41:00	PFR reports FAULTS : ATA 732141, SOURCE *EEC4B,IDENTIFIERS *EEC4A, CLASS 2, HARD, FUEL PUMP, FUEL LP SW	PFR (HKG-AMS)	
06/02/2005	03:41:08	Engine 4 N1 reduces to 48 %	FDR	
09/03/2005	03:41:14	"its number four "	CVR	
09/03/2005	03:41:24	"opening the cross feeds ",	CVR	
06/02/2005	03:41:26	Engine 4 N1 returns to 80 %	FDR	
06/02/2005	03:41:29	ECAM Fuel Page ON	FDR	ECAM DISPLAY MODE - MANUAL
09/03/2005	03:41:42	"there's a fuel management problem "	CVR	
09/03/2005	03:44:28	"engine relight in flight.. max guaranteed altitude thirty th	CVR	
06/02/2005	03:45:00	PFR reports COCKPIT EFFECT : ATA 7305 ENG 1 MINOR FAULT	PFR (HKG-AMS)	
06/02/2005	03:45:00	PFR reports FAULTS : ATA 732152, SOURCE EEC1A, CLASS 1, HARD, HMU, AUTOSTART SOV TK A	PFR (HKG-AMS)	attempted and failed restart of engine 1 due to altitude FL380
06/02/2005	03:45:11	Engine 1 Master ON	FDR	
06/02/2005	03:46:00	PFR reports COCKPIT EFFECT : ATA 8000 ENG 1 START FAULT	PFR (HKG-AMS)	
06/02/2005	03:46:00	Master CAUTION	FDR	
06/02/2005	03:46:41	Engine 1 Master OFF	FDR	
06/02/2005	03:46:41	ECAM Secondary Engine Page ON then returns to ECAM Fuel Page	FDR	
06/02/2005	03:47:00	FCMC 2 CMP fails FUEL, TRIM TK ISOL VALVE due FAILED OPEN	TSD FCMC 2 16/08 and TSD FCMC 2 A/C 5/37	
09/03/2005	03:47:06	"and open … . we have to do that as well "	CVR	
09/03/2005	03:48:21	"we got some fuel coming in to .. one and four .. "	CVR	
06/02/2005	03:49:25	Trim tank contents starts to decrease.	FDR	
06/02/2005	03:49:25	Left and Right Outer start to decrease.	FDR	
06/02/2005	03:49:25	Inner 1,2,3 & 4 all start to increase.	FDR	
06/02/2005	03:49:25	Center starts to increase.	FDR	
06/02/2005	03:49:21	Aircraft descent initiated	FDR	
09/03/2005	03:49:30	MAYDAY call	CVR	
09/03/2005	03:50:06	"it isn't transferring forward.. would you agree with that "	CVR	
09/03/2005	03:51:28	crew then referred to a "trim tank transfer fault" procedur	CVR	
09/03/2005	03:52:53	"to put that back to auto "	CVR	
09/03/2005	03:57:26	"we don't know whether it's coming out "	CVR	
06/02/2005	04:03:00	Both Left and Right Outer = zero	FDR	trim = 3679, Left Outer = 0, Right Outer = 0, Center = 5864, 1 inner = 2149, 2 inner = 5263, 3 inner = 4935, 4 inner = 1856, total = 23688
06/02/2005	04:10:00	landing at Amsterdam	tech log report 1201304	
06/02/2005	04:10:25	TOUCHDOWN	FDR	trim = 2119, Left Outer = 0, Right Outer = 0, Center = 4325, 1 inner = 2641, 2 inner = 5922, 3 inner = 5373, 4 inner = 2583, total = 22963
06/02/2005	04:11:00	FCMC 2 CMP fails FUEL, INR 3 XFR CNTRL VLV due FAILED SHUT	TSD FCMC 2 15/08 and TSD FCMC 2 A/C 5/37	
06/02/2005	04:11:00	FCMC 2 CMP fails FUEL, INR 2 XFR CNTRL VLV due FAILED SHUT	TSD FCMC 2 16/08 and and TSD FCMC 2 A/C 7/37	
06/02/2005	04:11:00	FCMC 1 CMP fails FUEL, INR 3 XFR CNTRL VLV due FAILED SHUT	TSD FCMC 1 5/27 and TSD FCMC 1 A/C 1/04	
06/02/2005	04:11:00	FCMC 1 CMP fails FUEL, INR 2 XFR CNTRL VLV due FAILED SHUT	TSD FCMC 1 6/27 and TSD FCMC 1 A/C 2/04	
06/02/2005	04:13:00	PFR reports end of VHHH - EGLL DIVERT EHAM sector	PFR (HKG-AMS)	
06/02/2005	04:25:00	FCMC 2 CMP fails FUEL, CTR TK L XFR PUMP due FAILED OFF	TSD FCMC 2 A/C 1/37	
06/02/2005	04:25:00	FCMC 2 CMP fails FUEL, INR TK 4 XFR VALVE due FAILED SHUT	TSD FCMC 2 A/C 2/37	
06/02/2005	04:25:00	FCMC 2 CMP fails FUEL, INR TK 3 XFR VALVE due FAILED SHUT	TSD FCMC 2 A/C 3/37	
06/02/2005	04:25:00	FCMC 2 CMP fails FUEL, INR TK 2 XFR VALVE due FAILED SHUT	TSD FCMC 2 A/C 4/37	
06/02/2005	04:40:00	on blocks at Amsterdam	tech log report 1201304	
06/02/2005	04:50:00	fuel FCMC 2 reset unsuccessful. NB FDC 2 cleared on its own. FCMC 1 and 2 reset both test	tech log 1201304	
06/02/2005	20:00:00	Refuel of aircraft. Pre refuel: 20600, Uplift: 20970, Depart:40000	Tech log 1201306	
06/02/2005	20:32:00	off blocks at AMS	tech log 1201307	
06/02/2005	20:39:00	FCMC 1 CMP fails FCMC 1 due FUEL TEMP IND FAIL	TSD FCMC 1 4/23	
06/02/2005	20:39:00	Previous leg report for FCMC 2 reports start of VHAM - EGLL sector	Previous leg report FCMC 2 a/c	
06/02/2005	20:40:00	FCMC 2 CMP fails FUEL, INR TK 4 TEMP SNSR due FQI TEMP AB COMPARE FAIL	TSD FCMC 2 13/08	
06/02/2005	20:40:00	FCMC 1 CMP fails FUEL, INR TK 4 TEMP SNSR due FQI TEMP AB COMPARE FAIL	TSD FCMC 1 3/27	
06/02/2005	20:42:00	FWC2 fails FCMC4 due No Refresh Arinc Bus as External Failure occ 1	TSD FWC 2	
06/02/2005	20:43:00	FCMC 1 CMP fails FUEL, INR TK 4 TEMP SNSR due FQI TEMP AB COMPARE FAIL	TSD FCMC 1 2/27	
06/02/2005	20:44:00	FCMC 1 CMP fails FUEL, INR TK 4 TEMP SNSR due FQI TEMP B OUT OF RANGE	TSD FCMC 1 27/07	
06/02/2005	20:54:00	take off from AMS	tech log 1201307	
06/02/2005	20:55:00	FWC1 fails due Arinc Bus as Start occ 1	TSD FWC 1	
06/02/2005	20:55:08	TSD DMC 1 Error code : 65 BITE message : POWER_SUPPLY_INTERRUPT ATA : 240000 Occurrences : 1 Event : 2 => no communication from DMC to DMC subscribers (DUs,…)	TSD DMC 1	
06/02/2005	22:32:00	landing at LHR	tech log 1201307	
06/02/2005	22:35:00	Previous leg report for FCMC 2 reports end of VHAM - EGLL sector	Previous leg report FCMC 2 a/c	
06/02/2005	22:40:00	on blocks at LHR	tech log 1201307	

FAA Notice of Proposed Rulemaking (NPRM)
Excerpts From Notice No 87-3

The following passages are excerpts from the FAA Notice of Proposed Rulemaking (NPRM) published in the Federal Register Vol 52, No 91 on Tuesday 12 May 1987 on pages 17890 through 17893:

"DEPARTMENT OF TRANSPORTATION Federal Aviation Administration 14 CFR Part 25

[Docket No. 25263; Notice No. 87-31 Low Fuel Quantity Alerting System

AGENCY: Federal Aviation Administration (FAA). DOT.

ACTION: Notice of proposed rulemaking (NPRM).

SUMMARY: This notice proposes to amend the airworthiness standards for transport category airplanes by requiring a means to alert the flightcrew of potentially unsafe low fuel quantities. There have been several recent fuel depletion incidents involving loss of power or thrust on all engines that could have resulted in forced landings and injury or loss of life. Most of these incidents resulted from improper fuel management techniques. This proposal would require new transport category airplane designs to incorporate a low fuel quantity alert to the flightcrew that would allow either correction of certain fuel management errors or the opportunity to make a safe landing prior to engine fuel starvation.

DATE: Comments must be received on or before September 9, 1987…

…Background

Section 25.955(b) of the Federal Aviation Regulations (FAR) requires an airplane fuel system that is designed to prevent interruption of fuel flow to an engine without attention by the flightcrew, when any fuel tank supplying fuel to that engine is depleted of usable fuel during normal operation, and any other tank that normally supplies fuel to that engine contains usable fuel. Although this requirement ensures that a continuous fuel supply is available during normal operation, it does not ensure a continuous fuel supply in all fuel-feed configurations.

With the development of more complex aircraft fuel systems and fuel management techniques, the need for a low fuel quantity alerting system has become evident. A review of transport airplane operational problems has revealed a number of fuel feed system depletion incidents. Five recent incidents involved the loss of power or thrust on all engines, and each had the potential for a catastrophic result. The causes of these incidents have included fuel quantity indication system service difficulties, inadequate pre-flight preparation, and flightcrew inattention to fuel management.

In several of these instances, a low fuel level alerting system could have provided the flightcrew with the opportunity to take appropriate corrective action prior to engine fuel starvation.

Additionally, the advent of electronic instruments has made possible direct-reading digital displays which, while they provide an accurate quantitative reading, may not provide sensory cues to the flightcrew that are as effective as those provided by analog displays. For example, analog displays facilitate rapid cross-checking of the fuel quantities in several tanks. Furthermore, the flightcrew's capability to effectively monitor fuel quantity is diminished in cockpit designs where the fuel quantity displays are in the pilot's overhead panel.

Many airplane designers have recognized that a low fuel quantity alerting system is a proper and desirable fuel system design, and some recently certificated airplanes have incorporated such a system.

Section 25.1305 of the FAR specifies the required powerplant instruments for transport category airplanes. These include a fuel quantity indicator for each fuel tank; however, there is currently no additional requirement to annunciate a low fuel state to the flightcrew. The proposed amendment would add a requirement for a cautionary alert to indicate low fuel quantity.

To preclude unintentional engine power loss due to fuel depletion resulting from fuel mismanagement or other causes while substantial fuel remains in the airplane, a low fuel alerting system would be required for any tank that normally should not be depleted of usable fuel. The FAA considers this approach to be appropriate because in using approved fuel management procedures, certain fuel tanks are expected to be depleted of usable fuel with no resultant interruption of fuel to the engine. A low fuel cautionary alert on these tanks would be unnecessary and considered a nuisance. For example, fuel tanks that do not feed directly to engines or tanks with boost pump pressure which overrides boost pump pressure from other tanks and are normally emptied first need not have a low fuel alerting system. Therefore, the proposed rule is not intended to require a low fuel alerting device for each fuel tank.

A low fuel alerting system based on total fuel remaining in the system, irrespective of which tank contains the fuel, is considered inadequate. While it would provide indication of impending total fuel depletion, no alert would occur if the fuel in a tank feeding an engine is depleted due to fuel-feed mismanagement while a significant amount of fuel remains available in another tank.

The proposed amendment would require the low fuel alerting system to be independent of the normal fuel quantity measurement system. There have been instances in which fuel quantity systems have provided inaccurate information due to wiring harnesses being inadvertently switched or the system becoming disabled. An effective low fuel quantity alerting system should be protected from

these types of malfunctions. The alerting system would probably incorporate a test feature to ensure functional reliability. Therefore, as proposed, no malfunction or failure of the normal fuel quantity measuring system would prevent proper operation of the low fuel quantity alerting system.

As proposed, the alert must occur with no Iess fuel remaining in the tank than that required to operate the engine(s) which can be supplied by that tank for 30 minutes at normal cruising conditions. A low fuel alert would not occur under normal circumstances because fuel reserves are usually in excess of the fuel quantity specified by this requirement. If a low fuel alert occurs due to fuel mismanagement or other factors, the flightcrew would have at least 30 minutes to correct the situation or to land at a suitable airport…

…The Proposed Amendment

Accordingly, the Federal Aviation Administration (FAA) proposes to amend Part 25 of the Federal Aviation Regulations (FAR) 14 CFR Part 25, as follows:

PART 25-AIRWORTHINESS

STANDARDS: TRANSPORT CATEGORY AIRPLANES

The authority citation for Part25 continues to read as follows:

Authority: 49 U.S.C. 1344, 1354(a), 1355, 1421, 1423, 1424, 1425, 1428, 1429, 1430: 49 U.S.C. 108(g) (Revised Pub. L. 97-449, January 12, 1983): and 49 CFR 1.47(a).

By amending § 25.1305 by adding a new paragraph (a) (9) to read as follows:

g 25.1305 Powerplant Instruments.

* * * *

(a) * * *

(9) A means to provide a cautionary alert to the flightcrew of a low fuel quantity in any fuel tank that normally should not be depleted of usable fuel. The alerting system shall operate independently of the fuel quantity measuring system. The alert shall commence at a time appropriate to the type of airplane and the intended operation, but shall be prior to that time when the-remaining fuel reaches the quantity required to operate the engines) being supplied by that tank for 30 minutes at normal cruising conditions.

FAA Notice No 87-3 Withdrawl of NPRM

The following text is the withdrawal of NPRM 87-3, published in the Federal Register on
16 August 2002.

DEPARTMENT OF TRANSPORTATION

Federal Aviation Administration

14 CFR Part 25

[Docket No. 25263; Notice No. 87-3]
RIN 2120-AB46

Low Fuel Quantity Alerting System

AGENCY: Federal Aviation Administration (FAA), DOT.

ACTION: Notice of proposed rulemaking (NPRM); withdrawal.

SUMMARY: The FAA is withdrawing a previously published Notice of Proposed Rulemaking
(NPRM) to amend airworthiness standards for transport category airplanes by requiring a means to
alert the flight crew to potentially unsafe low fuel quantities. We are withdrawing the proposed rule
because information has been surpassed by technological advances. The issues will be addressed
by future regulatory action based on recommendations from the Aviation Rulemaking Advisory
Committee (ARAC). The FAA has determined that future regulatory action, including the broader
scope of a harmonized proposal, will better serve the public interest.

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SUPPLEMENTARY INFORMATION

Background

On May 12, 1987, the FAA published Notice of Proposed Rulemaking No. 87-3 (52 FR 17890)
to propose an amendment to part 25 of title 14, Code of Federal Regulations, and invited public
comment on the subject of a low fuel quantity alerting system. Notice No. 87-3 proposes to amend
airworthiness standards for transport category airplanes by requiring a means to alert the flight crew
to potentially unsafe low fuel quantities. The alerting system would be required to be independent
of the normal fuel quantity measurement system, and the alert would have to occur with no less fuel
remaining than that required to operate for 30 minutes at normal cruising conditions. The comment
period closed September 9, 1987.

Discussion of Comments

Ten comments were received in response to the NPRM. In general, most commenters were in favor of the NPRM for the low fuel quantity alerting system, with a few commenters suggesting additional enhancements to the proposal.

Of the commenters that express support for the proposal, one urges a similar rule change to parts 23, 121, and 135 of title 14 of the Code of Federal Regulations. Of the commenters who feel additional technology is warranted, one recommends a review and application to existing aircraft, another recommends an annual calibration check of the system, and another offers some design considerations. Several commenters find the cost estimation to be underestimated in the NPRM.

Two commenters support the proposal and state that the phrase "30 minutes at normal cruising conditions" needs clarification. Another two commenters object to the same phrase, but oppose the proposal, because it only applies to one configuration and one altitude. Both of these commenters assert that the proposal should only apply to air carriers whose aircraft weigh over 75,000 pounds.

The FAA acknowledges these contributions to the rulemaking process, and affirms its commitment to aviation safety by continuing to clarify, update, and harmonize its regulations. We will address any remaining concerns in future regulatory actions as we pursue global harmonization of aviation regulations.

ICAO and Harmonization

The International Civil Aviation Organization (ICAO) established the International Standards and Recommended Practices to promote international cooperation towards the highest possible degree of uniformity in regulations and standards. Thirty-two States and authorities joined in the goal of standardization.

The FAA and the Joint Aviation Authorities (JAA) of Europe came together to standardize their respective codes of regulation and identified a number of significant regulatory differences. Both consider harmonization of the two codes a high priority. In 1999, the FAA and JAA agreed on a Fast Track Harmonization Program to expedite the standardization process. ICAO Resolution A29-3, Global Rule Harmonization, urges States to take positive action to promote global harmonization of national rules for application of ICAO standards. The FAA actively supports ICAO initiatives and programs to achieve a safe and efficient aviation system worldwide.

Reason for Withdrawal

The FAA is involved in eliminating unnecessary differences and harmonizing, where practical, similar requirements with Europe andTransport Canada. We find that including the issues of Notice No. 87-3 within harmonization efforts assigned to ARAC will contribute to a more complete and current analysis of the issues that will better serve the public interest. In addition, future regulatory action will allow the public to benefit from the inclusion of technological advances relevant to the issues. To achieve harmonization goals and address technological issues, we will propose future

changes to the Code of Federal Regulations through an NPRM with opportunity for public comment. Therefore, the FAA withdraws Notice No. 87-3 (52 FR 17890), published May 12, 1987.

Issued in Washington, DC, on August 16, 2002.
Ronald T. Wojnar,
Deputy Director, Aircraft Certification Service (AIR-1).
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FAA Response to Safety Recommendations 2005-110 and 205-111

Federal Aviation Administration

Memorandum

Date: March 20, 2006

To Manager, Recommendation and Safety Analysis Division, AAI-200

From: Acting Manager, Safety Management Branch,
   Transport Airplane Directorate, ANM-117

Prepared by:
Subject: Response to AAI Safety Recommendation No. 06.006 & 06.007

This is a final response to FAA Safety Recommendation 06.006 and 06.007. The safety recommendations resulted from an Airbus A340-600 incident February 8, 2005, in which an engine lost power due to fuel starvation.

The two Safety Recommendations from the Air Accidents Investigation Branch (AAIB) of the UK are as follows:

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). [06.006]

The Federal Aviation Administration should review all aircraft currently certified to FAR-25 to ensure that if an engine fuel feed warning system is installed, it is independent of the fuel control quantity indication system(s). [06.007]

FAA Response to 06.006
As noted within the Discussion section of the AAIB Safety Recommendation (File Ref:EW/C2005/02/03): *"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 para c.".* The AAIB goes on to state that: *"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".*

Compliance with § 25.1309(c) is just as relevant during any anticipated failure condition as it is when the system is operating normally. Traditional designs may not have effectively met the intent of §25.1309(c) for certain "unsafe system operating conditions", including "low fuel level in an engine feeder tank". As evidenced by the Notice of Proposed Rulemaking (NPRM) (No. 87-3) published in the Federal Register on May 12, 1987 (52 FR 17890), titled *"Low Fuel*

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Quantity Alerting System Requirements for Transport Category Airplanes", the FAA once agreed with the AAIB that this "demonstrated a need for more specific requirements".

While adding a more specific rule may focus special attention and unique provisions onto a particular "unsafe system operating condition", it would not relieve an applicant of the obligation of complying with §25.1309(c) for that condition. After considering the comments from NPRM 87-3 and reviewing all the relevant service history, the FAA has concluded that there is no need for any new regulatory provisions in this case. The addition of a more specific requirement would be redundant to those regulatory objectives already covered by §25.1309(c). Furthermore, promulgation of a more specific requirement could inadvertently impede future design innovation and would not be an efficient use of our limited rulemaking resources.

The FAA now intends to develop clearer §25.1309(c) compliance guidance in the form of an interpretive policy on this issue. Successful completion of that action would effectively address FAA Safety Recommendation 06.006.

FAA Response to 06.007
While in most instances the recommended independence constitutes good design practice, lack of such independence does not inherently render a design unsafe. Hence, universally mandating such independence would not be warranted under FAR Part 39. However, we continually review the operating safety of the transport airplane fleet. If an unsafe condition exists, we take appropriate mandatory corrective action.

We trust that this information is sufficient to address the concerns of the AAIB with regard to the two safety recommendations.

If further discussion on this subject is needed, please contact   Manager, Propulsion and Mechanical Systems Branch, ANM-112, at (425) 227-2192 or   of the Safety Management Branch, ANM-117, at (425) 227-2134.