Air Accidents Investigation Branch

Accident Report No: 2/2008 (EW/C2005/10/05)

Registered Owner and Operator:	British Airways PLC
Aircraft Type and Model:	Airbus A319-131
Registration:	G-EUOB
Manufacturer's Serial Number:	1529
Place of Incident:	During the climb after departure from London Heathrow
Date and Time:	22 October 2005 at 1926 hrs (All times in this report are UTC, unless otherwise stated)

Contents

GLOSSARY OF ABBREVIATIONS USED IN THIS REPORT

AAIB	Air Accidents Investigation Branch
AC	Alternating Current
ACP	Audio Control Panel
ADF	Automatic Direction Finding
AIDS	Aircraft Integrated Data System
ALTN	Alternate
AMM	Aircraft Maintenance Manual
AMU	Audio Management Unit
ANR	Active Noise Reduction
APU	Auxiliary Power Unit
ASR	Air Safety Report
ATC	Air Traffic Control
BAT	Battery
BEA	Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation Civile
BITE	Built-In Test Equipment
BMC	Bleed (air) Monitoring Computer
BTC	Bus Tie Contactor
CAA	Civil Aviation Authority
CAS	Computed Air Speed
CFDIU	Centralised Fault Display Interface Unit
CFDS	Centralised Fault Display System
CMC	Central Maintenance Computer
CRT	Cathode-Ray Tube
CVR	Cockpit Voice Recorder
DAR	Direct Access Recorder
DC	Direct Current
DFDR	Digital Flight Data Recorder
DMC	Display Management Computer
DME	Distance Measuring Equipment
DP	Differential Protection
DU	Display Unit
EASA	European Aviation Safety Agency
EEC	Engine Electronic Controller
ECAM	Electronic Centralised Aircraft Monitoring
(E)EPGS	(Enhanced) Electrical Power Generation System
EFIS	Electronic Flight Instrument System
EGPWS	Enhanced Ground Proximity Warning System
EIS	Electronic Instrument System
EIU	Engine Interface Unit
EPR	Engine Pressure Ratio
ESS	Essential
EWD	Engine/Warning Display
FAC	Flight Augmentation Computer
FADEC	Full Authority Digital Engine Control
FCDC	Flight Control Data Concentrator
FDR	Flight Data Recorder
FOSD	Flight Operations Safety Department
FQI	Fuel Quantity Indicating
FL	Flight Level
FMC	Flight Management Computer
FMGC	Flight Management and Guidance Computer
fpm	feet per minute
FWC	Flight Warning Computer
GCU	Generator Control Unit
GLC	Generator Line Contactor
hrs	hour(s)
IAS	Indicated Air Speed
ICAO	International Civil Aviation Organisation
IDG	Integrated Drive Generator
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
ISIS	Integrated Standby Instrument System
JAR	Joint Aviation Requirements

GLOSSARY OF ABBREVIATIONS USED IN THIS REPORT (Continued)

kg	kilogram(s)
kt	knot(s)
LAM TC	Lambourne Terminal Control
LCD	Liquid Crystal Display
Maintrol	Maintenance Control
MCDU	Multi-purpose Control and Display Unit
MEL	Minimum Equipment List
METAR	Actual recorded weather at a specified location
MHz	Megahertz
min	minute(s)
MMEL	Master Minimum Equipment List
MOR	Mandatory Occurrence Reporting
MSN	Manufacturer's Serial Number
N_1	Low pressure engine rotor speed
ND	Navigation Display
nm	nautical mile(s)
NVM	Non-Volatile Memory
PF	Pilot Flying
PFD	Primary Flight Display
PFR	Post-Flight Report
PHC	Probe Heat Computer
P/N	Part number
PNF	Pilot not Flying
PR	Power Ready (relay)
psi	pounds per square inch
QNH	pressure setting to indicate elevation above mean sea level
QRH	Quick Reference Handbook
RA	Radio Altimeter
RAT	Ram Air Turbine
RMP	Radio Management Panel
SDAC	System Data Acquisition Concentrator
SFCC	Slat Flap Control Computer
SIGMET	Significant weather warning
SOP	Standard Operating Procedure
SVCE	Service
TCAS	Traffic Alert and Collision Avoidance System
TFU	Technical Follow Up
TR	Transformer Rectifier
UK	United Kingdom
UTC	Universal Time Coordinated
VHF	Very High Frequency
VMC	Visual Meteorological Conditions
V/S	Vertical Speed
WHC	Window Heat Computer
WNS	World Network Services
ºC, ºM	Degrees Celsius, Magnetic

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Synopsis

The incident occurred at 1926 hrs on 22 October 2005, to an Airbus A319-131 aircraft which was operating a scheduled passenger flight between London Heathrow and Budapest. The following Inspectors participated in the investigation:

Mr A P Simmons	Investigator-in-Charge
Ms G M Dean	Operations
Mr R G Ross	Engineering
Mr P Wivell	Flight Recorders

As the aircraft climbed to Flight Level (FL) 200 in night Visual Meteorological Conditions (VMC) with autopilot and autothrust engaged, there was a major electrical failure. This resulted in the loss or degradation of a number of important aircraft systems. The crew reported that both the commander's and co-pilot's Primary Flight Displays (PFD) and Navigation Displays (ND) went blank, as did the upper ECAM[1] display. The autopilot and autothrust systems disconnected, the VHF radio and intercom were inoperative and most of the cockpit lighting went off. There were several other more minor concurrent failures.

1 Electronic Centralised Aircraft Monitoring system - this comprises two centrally mounted electronic display units, which present the flight crew with aircraft systems information, warning and memo messages and actions to be taken in response to systems failures.

The commander maintained control of the aircraft, flying by reference to the visible night horizon and the standby instruments, which were difficult to see in the poor light. The co-pilot carried out the abnormal checklist actions which appeared on the lower ECAM display; the only available electronic flight display. Most of the affected systems were restored after approximately 90 seconds, when the co-pilot selected the AC Essential Feed switch to Alternate ('ALTN'). There were no injuries to any of the 76 passengers or 6 crew. After the event, and following discussions between the crew and the operator's Maintenance Control, the aircraft continued to Budapest.

The Air Accidents Investigation Branch (AAIB) became aware of this incident on 28 October 2005, through the UK Civil Aviation Authority's Mandatory Occurrence Reporting (MOR) scheme. The AAIB investigation team was assisted by an Accredited Representative from the Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation Civile (BEA, the French air accident investigation authority) and by the aircraft manufacturer.

Preliminary information on the progress of the investigation was published in AAIB Special Bulletins S2/2005 and S3/2006, in November 2005 and April 2006. Four Safety Recommendations were made in Special Bulletin S3/2006.

It was not possible to determine the cause of the incident due to a lack of available evidence, however, nine additional Safety Recommendations are made in this report.

1 Factual Information

1.1 History of the flight

The aircraft departed London Heathrow Airport at 1918 hrs on a scheduled night flight to Budapest, with 76 passengers and 6 crew on board. The incident occurred at 1926 hrs, as the aircraft was approaching FL 200 in the climb, in clear weather conditions. The crew reported that there was an audible 'CLUNK' and the flight deck suddenly became very dark, with a number of systems and flight information displays ceasing to function. The following symptoms were reported:

- Loss of the pilot's and the co-pilot's PFDs, NDs and the ECAM upper display, leaving only the ECAM lower display available;
- Loss of the No 1 autopilot; the associated aural Master Warning tone sounded;
- Loss of autothrust; the associated aural Master Warning tone sounded;
- Loss of the No 1 VHF radio, which was in use at the time, and the loss of the flight interphone;
- Loss of most of the flight deck lighting including the integral lights on the glareshield, the overhead and pedestal panels and the integral lighting for the standby instruments;
- The cabin lights went out momentarily and the emergency lights came on;
- A number of other, less critical systems were also affected.

The commander, who was in the left seat and was the Pilot Flying (PF), observed that both his and the co-pilot's instrument displays had blanked. He retained control and flew the aircraft by reference to the external night horizon, the standby horizon and the standby altimeter. The standby instruments were poorly illuminated by what little cockpit lighting remained. The commander maintained the aircraft attitude, set manual thrust and continued the climb to FL 230, the last level to which he recalled having been cleared. He tried to transmit a 'MAYDAY' call on the No 1 VHF radio; however, it was not received by Air Traffic Control (ATC) because the radio was no longer powered. On the first attempt he inadvertently pushed the autopilot disconnect switch on his sidestick instead of the press-to-transmit button, but on hearing the aural alert 'PRIORITY LEFT' he realised his error and attempted to transmit again. The aircraft's transponder signal was also lost, prompting ATC to attempt to contact the aircraft, but they received no reply.

The commander concentrated on flying the aircraft whilst the co-pilot worked sequentially through the checklist actions that had appeared automatically on the lower ECAM display. The pilots were using Active Noise Reduction (ANR) headsets and the loss of the flight interphone made communication between them difficult. The co-pilot had difficulty in identifying some of the switch locations on the overhead panel because of the lack of lighting, but was able to carry out the ECAM checklist actions. Emergency torches were available to the crew, but were not used. Most of the affected systems were restored after about 90 seconds, when the co-pilot selected the AC ESS FEED push button switch to 'ALTN' (Alternate). This was the ninth or tenth line on the ECAM display. The commander and co-pilot's primary flight displays and navigation displays, the upper ECAM display, radio, transponder and most of the other affected systems were then recovered. The co-pilot continued the ECAM actions and the No 1 generator, which had dropped off line, was reset. The autothrust system was not reinstated and it was necessary to control the engine thrust manually for the remainder of the flight.

As communications were now re-established, the commander transmitted a 'PAN' call to ATC advising them of the problems experienced with the aircraft; he was instructed to maintain the current altitude and heading. He then requested and was allocated a holding pattern, to allow the crew time to review the status of the aircraft. The commander handed over control of the aircraft to the co-pilot, so that he could assess the situation. Whilst in the hold, the cabin crew and passengers were briefed as to the situation and the Auxiliary Power Unit (APU) was started as a precaution so that its generator would be available to provide electrical power if required, but it was not used.

The commander recalled that the ECAM indicated that the following systems remained degraded or inoperative after selection of the AC ESS FEED switch and the reinstatement of the No 1 generator : autothrust, No 1 Transformer Rectifier[1] (TR 1), left side window and windscreen heat, cabin temperature control, avionics ventilation and lavatory and galley ventilation. In addition, the Engine Pressure Ratio (EPR) mode of engine control was unavailable and

1 Some of the aircraft's systems require direct current electrical power. A transformer rectifier is a device which converts the alternating current produced by a generator into direct current.

the engines had degraded to the N_1[2] control mode. When the ECAM electrical system synoptic page was reviewed, everything appeared to be normal, with the exception of TR 1, which was highlighted in amber.

The commander contacted the operator's duty Maintenance Control (Maintrol) engineer on the VHF radio for technical advice. Communication was difficult and the aircraft remained in the hold for some 40 minutes while the commander and engineer exchanged information. The commander advised Maintrol that he believed the primary fault was the TR 1 and that the other failures were ancillary. Much of the discussion was concerned with whether the flight should continue to Budapest. Maintrol advised that it should be possible to reset TR 1 on the ground and that onward dispatch for the next sector would be possible.

The commander made the decision to continue the flight to Budapest. He carried out the approach at Budapest and control was handed over to the co-pilot for the landing; this was a company Standard Operating Procedure (SOP). The windshield and the left side window had misted or iced over and therefore his forward view was restricted. The aircraft landed at Budapest at 2154 hrs; during the otherwise uneventful landing roll the crew observed a thrust reverser amber caution on the ECAM. The co-pilot taxied the aircraft to the terminal because of the restricted visibility on the commander's side.

After shutdown, the commander completed the technical log and had discussions with the local station engineer. He and the rest of the crew then left the aircraft. He considered making a telephone call to the operator's fleet office to advise them of the problems he had experienced but, because it was a Saturday night, he decided to leave it until a more convenient time.

1.2 Injuries to persons

There were no injuries to any persons.

1.3 Damage to aircraft

The aircraft was not damaged.

1.4 Other damage

None.

2 The control logic for the management of engine thrust normally references the Engine Pressure Ratio (EPR) parameter. In the alternate mode the thrust is controlled with reference to the engine low pressure rotor speed, (N_1).

1.5 Personnel information

1.5.1 Commander

Male:	Age 53 years
Licence:	Airline Transport Pilot's Licence
Aircraft ratings:	Airbus A320-series, Boeing 757/767
Licence Proficiency Check:	Valid to 30 September 2006
Operational Proficiency Check:	Valid to 31 March 2006
Annual Line Check:	Valid to 31 May 2006
Medical Certificate:	Class 1 Valid
Flying Experience:	Total - 11,800 hours (of which 4,000 were on type)
	Last 90 days 180 hours
	Last 28 days 70 hours
	Last 24 hours 4 hours
Previous rest period:	16 hours

The commander reported for duty at 1135 hrs and at the time of the incident had been on duty for 7 hours 51 minutes.

1.5.2 Co-pilot

Female:	Age 29 years
Licence:	Airline Transport Pilot's Licence
Aircraft ratings:	Airbus A320-series
Licence Proficiency Check:	Valid to 30 August 2006
Operational Proficiency Check:	Valid to 31 March 2006
Annual Line Check:	Valid to 31 October 2006
Medical Certificate:	Class 1 Valid
Flying Experience:	Total - 2,000 hours (of which 1,780 were on type)
	Last 90 days 190 hours
	Last 28 days 60 hours
	Last 24 hours 4 hours
Previous rest period:	24 hours

The co-pilot reported for duty at 1140 hrs and at the time of the incident had been on duty for 7 hours 46 minutes.

1.5.3 Training

1.5.3.1 General

Both crew members had completed simulator training in electrical system failures but neither had previous experience of a failure which involved so many of the essential flight displays being lost.

1.5.3.2 Pilot training on standby instruments

Neither pilot could recollect having received any specific training on flight with sole reference to the standby instruments during the period they had been operating A320 family aircraft.

The investigation team were informed by Airbus that on the company's own initial type training courses, pilots are not given any training on how to fly the aircraft by sole reference to the standby instruments. This is considered by Airbus to be a basic flying skill that all pilots should already possess and thus, in Airbus's opinion, does not require special training.

1.6 Aircraft information

1.6.1 Leading particulars

Registration:	G-EUOB
Type:	Airbus A319-131
Manufacturer's Serial Number:	1529
Year of Manufacture:	2001
Airframe life at time of incident:	10,058 flying hours/7,818 landings
Engines:	2 IAE V2522-A5 turbofan engines

The A319 belongs to the A320 family of aircraft, which includes the A318, A319, and A321. The A320 was the first to receive certification; the other aircraft are derivatives of the A320 and there is much commonality between them.

G-EUOB held a valid Certificate of Airworthiness in the Public Transport category. It was maintained by the airline's own EASA-approved maintenance organisation, in accordance with EASA-145 Approved Maintenance Schedule ATP 3557 Revision 0.

The aircraft was not carrying any deferred defects relevant to this incident. The fuel on board at departure was 13,400 kg and on landing was 6,500 kg.

1.6.2 Post-flight defect reporting

After arrival at Budapest, the commander made an entry in the 'Defect Symptom' column of the aircraft technical log. He did not record the full details of the event, rather only those defects that remained outstanding, as follows:

Defect No 1: 'ASR raised - see subsequent entries'
Defect No 2: 'ENG 1 - EPR mode fault - N_1 degraded mode'
Defect No 3 'ELEC - TR 1 fault'

He also discussed the incident with the station engineer, who was employed by a local airline contracted to support the operator's aircraft in Budapest.

The corrective actions taken by the engineer included resetting TR 1 and performing tests of the No 1 (left) engine FADEC[3], the No 1 engine thrust reverser and the window and probe heat systems, all of which proved satisfactory. He completed the required 'Daily Inspection' on the aircraft at 0100 hours on 23 October 2006 and released the aircraft for further service.

The commander also raised an Air Safety Report (ASR) documenting the incident. He handed it to the station engineer, who gave it to a member of the airline's Customer Service staff for processing. The original was sent by post to the airline's Flight Operations Safety department at London Heathrow, arriving four days later. The processing procedure also required copies of the ASR to be faxed to the Flight Operations Safety department and to an organisation in Mumbai, India for entering onto the airline's safety management database; however, for reasons which could not be established, the faxed copies were not received.

When the commander returned to the UK the following day he telephoned his company's Airbus fleet office and spoke with a technical manager; this was to see if there was any follow up required from his ASR. The technical manger replied that he had not seen the ASR, so the commander gave him a detailed verbal account of the event. The technical manager responded by saying that he would await the ASR with interest but no further action was taken until the ASR was entered into the system three days later.

3 FADEC is an acronym for Full Authority Digital Engine Control, denoting that the engines are controlled by digital computers, which can store faults relating to engine performance and can also perform self-testing to verify their serviceability.

1.6.3 Maintenance history

A review of the aircraft's maintenance history did not identify any defects or recent maintenance actions relevant to the incident. There were no records of any previous similar incidents on this aircraft and there has not been a recurrence to date.

1.6.4 Aircraft examination and testing

The aircraft continued operating for several days after the incident, until 28 October 2005, when it was removed from service for examination and testing. This was overseen by the AAIB.

Given the reported symptoms, troubleshooting actions focussed on the aircraft's electrical systems. This included examination of the Integrated Drive Generator (IDG) feeder cable connectors in the engine pylons for evidence of poor contact or arcing, however none was found.

Electrical network switching checks were also performed, including tests of the automatic Bus Tie and AC Essential Feed functions. The former automatically configures one generator to supply both electrical networks in the event of a single generator failure and the latter reconfigures the No 2 (right) engine generator to supply the AC Essential bus, which provides electrical power to a number of critical systems on the aircraft. No anomalies were found during these checks.

On 30 October 2005, more detailed electrical system integrity checks were performed by the operator in accordance with Maintenance Manual Task 24-00-00-710-003, however no defects were found.

On 8 March 2006 further electrical system tests were performed; these were overseen by the AAIB and representatives from Airbus and the BEA. These also failed to identify any faults and it was not possible to reproduce the symptoms reported by the crew.

1.6.5 Aircraft electrical power system

1.6.5.1 General

The electrical power system broadly comprises two electrical networks, a left and a right, denoted No 1 and No 2, respectively. This nomenclature is also applied to the components within the respective systems. A third network, called the

Essential network, supplies certain essential aircraft systems and this is itself supplied by either No 1 or No 2 networks. Each network incorporates 115/200 volt AC supplies and 28 volt DC supplies. No 1 and No 2 networks are normally independent of one another, so that the failure of one network theoretically should not affect the other. The power supplies for flight critical systems are for the most part segregated, so that the loss of a single power source should not cause concurrent failures of systems necessary for continued safe flight.

The A320 family aircraft Electrical Power Generation System (EPGS) has undergone design changes with time, giving rise to two distinct configurations of EPGS. The original is referred to as the 'Classic' configuration and the more recent as the 'Enhanced' Electrical Power Generation System (EEPGS). The EEPGS was introduced on production aircraft through Airbus Modification No 27140. G-EUOB was equipped with the 'Classic' EPGS.

1.6.5.2 Power generation and distribution

In the normal flight configuration, each network receives AC power from a dedicated engine-driven generator. The generator is driven from the engine high pressure compressor via the engine accessory gearbox. An integrated hydro-mechanical speed regulator transforms variable engine speed into a constant-speed drive to operate the generator. The assembly is known as an Integrated Drive Generator. The APU is also equipped with a generator, which can be used to power a network if an engine driven generator fails. Each generator is connected to the network via a Generator Line Contactor[4] (GLC).

The two networks are subdivided into busses and sub-busses, based on their functionality (Figure 1). The IDGs supply three-phase 115/200 volt, 400 Hertz constant-frequency power to the left and right AC busses, AC BUS 1 and AC BUS 2. AC BUS 1 in turn, supplies the AC Essential bus (AC ESS) via the AC Essential Feed (AC ESS FEED) contactor. The AC ESS bus, in turn, supplies the AC ESS SHED bus.

For DC power generation, the AC output from the IDGs is fed to Transformer Rectifiers, which convert the AC voltage into 28 volts DC. AC BUS 1 supplies the No 1 Transformer Rectifier, which provides DC power to DC BUS 1 and the DC Battery bus (DC BAT). AC BUS 2 supplies TR 2, which supplies DC BUS 2 and the DC Service bus (DC SVCE). The DC Essential bus (DC ESS) normally receives its power from the DC BAT bus. The DC ESS bus, in turn, provides power to the DC ESS SHED bus.

4 A contactor is a type of high-current electrical relay.

Two 28 volt DC, 23 ampere-hour batteries are permanently connected to the hot battery busses, HOT BUS 1 and HOT BUS 2. When battery charging is required, the hot battery busses are automatically connected to the DC BAT bus through the closure of the battery contactors. When the batteries are fully charged, the battery charge limiter opens the battery contactors, disconnecting the batteries from the DC BAT bus.

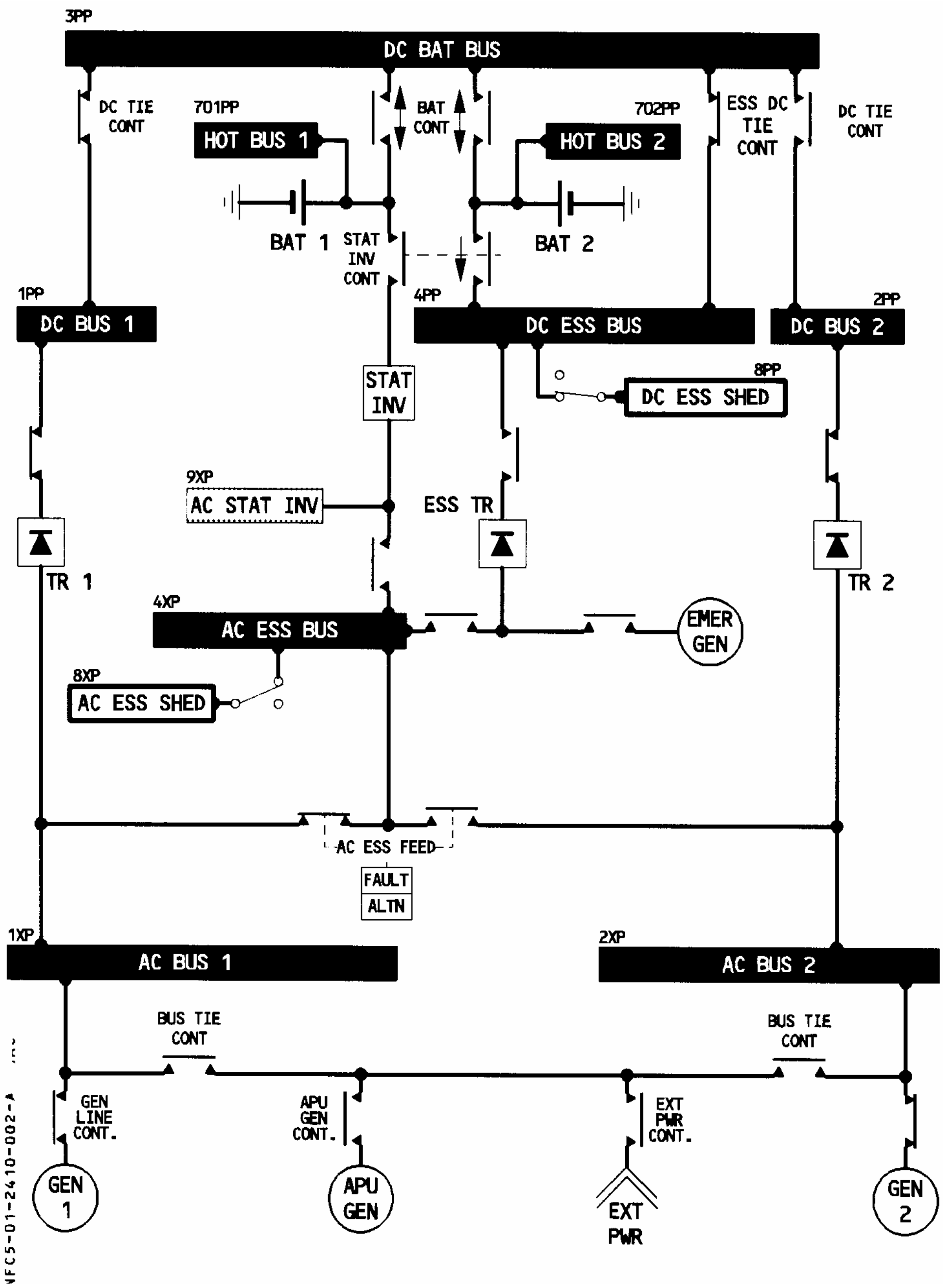

Figure 1

A319 Electrical System Architecture

(Normal Flight Configuration shown)

1.6.5.3 Control and indication

The electrical system is controlled via the electrical panel on the overhead console in the cockpit (Figure 2).

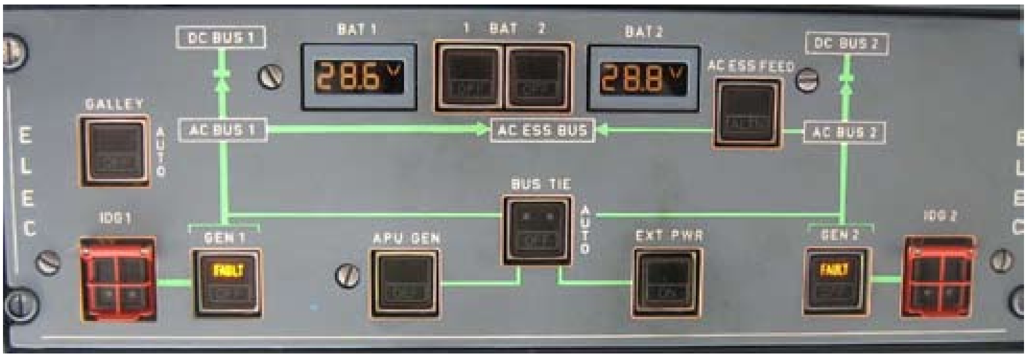

Figure 2

Electrical system control panel

The panel also provides for annunciation of the status of the electrical system and fault conditions. The generator control switches are identified as GEN 1, GEN 2 and APU GEN for the left, right and APU generators. If a fault occurs with a generator, a fault legend will illuminate on the respective generator control push button switch. Selection of a generator control switch causes its respective auxiliary relay to energise, which causes the GLC coil to be energised, coupling the generator to its on-side AC bus (AC BUS 1 or AC BUS 2). The AC ESS FEED push button switch is also located on this panel. If the AC ESS bus is unpowered, a fault legend will illuminate on the AC ESS FEED switch.

A synoptic display showing the status of the electrical power system can be shown on the lower ECAM screen and will automatically appear following an electrical failure. Normal system conditions are displayed in green or white and abnormal conditions appear in amber.

1.6.5.4 Electrical failure conditions

The segregation of power supplies to flight critical systems is arranged so that the loss of either the No 1 or No 2 electrical networks should not, in theory, cause the simultaneous loss of critical systems.

If GEN 1 or GEN 2 fail, both Bus Tie Contactors (BTC) are automatically closed by relay logic, allowing the affected network to be powered by the generator on the opposite side. In this condition, one engine-driven generator supplies power to both networks. Alternatively, if the APU generator is available (the APU must be running), the on-side BTC automatically closes so that the APU generator replaces the failed engine-driven generator.

Following an AC BUS 1 failure, reconfiguration of the power supplies can only be done manually. This is to prevent a fault in the left network causing the simultaneous loss of the right network. If AC BUS 1 fails, the AC ESS and DC ESS busses become unpowered and can be recovered by selecting the AC ESS FEED button to 'ALTN'. This causes the AC ESS FEED contactor[5] to operate, routing power from AC BUS 2 to supply the AC ESS bus. Relay logic causes the DC Bus Tie Contactors to automatically close after approximately five seconds, connecting DC BUS 2 to the DC BAT bus, so that DC BUS 1 receives power from the DC BAT bus instead of TR 1. The DC ESS bus is automatically transferred to the ESS TR via the ESS TR contactor.

In the event of the loss of both electrical networks in flight, an Emergency Generator, driven by hydraulic pressure provided by a Ram Air Turbine (RAT), can supply electrical power to the AC ESS bus for the systems essential for continued safe flight. The Emergency Generator also supplies the DC ESS bus through the Essential Transformer Rectifier. (ESS TR).

If no AC power generation sources are available, the aircraft batteries can provide a reduced amount of AC and DC electrical power for a limited period. In this case the AC ESS SHED and DC ESS SHED busses are automatically shed, to reduce the electrical loading and conserve battery power.

1.6.5.5 Network control and monitoring

Each electrical network is controlled and monitored by a dedicated Generator Control Unit[6] (GCU); this has the capability to store system fault data in non-volatile memory. The GCU has four main functions:

- regulation of the generator output voltage by controlling the field current
- generator control and protection of the generator and the electrical network

5 The AC Essential Feed contactor is a high current relay, which normally connects the AC ESS bus to the left AC bus (AC BUS 1). Selection of the AC ESS FEED push button switch to the 'ALTN' position cause the normally closed contacts to open, and by the movement of a rocker arm, the second set of contacts to close, routing AC BUS 2 power to the AC ESS bus.

6 The GCUs are digital computers which together control and monitor the electrical power supply network.

- control of warnings and indications for the electrical network
- self-monitoring and testing

GCU 1 controls the No 1 (left) and GCU 2 the No 2 (right) engine generator and electrical network.

If a GCU does not detect any fault in the network, an internal Power Ready (PR) relay is energised. This places power at the generator control switch (GEN 1, 2 or APU GEN) on the electrical control panel. Selection of the generator control switch will energise the respective auxiliary relay, which in turn energises the respective GLC, coupling the generator to its on-side AC bus.

If a fault is detected by a GCU, the PR relay is de-energised, causing its respective GLC to open, isolating the generator from the AC bus. A fault legend will illuminate on the respective generator control switch. In the event of a spurious fault, one attempt is permitted to reset the GCU by cycling the generator control switch on the electrical system control panel.

1.6.5.6 GCU differential protection function

One of the functions performed by the GCU is differential protection, the purpose of which is to protect the generator and network from damage in the event of a fault.

Differential protection is commonly applied in the design of three-phase AC electrical systems. It operates by comparing the electrical current on each phase at different points within the network. A significant difference between the measured currents on a phase is indicative of a fault, such as a short circuit.

In this application, the phase currents are measured at the IDG, at a point upstream of the GLC and at a point downstream of the GLC; the latter gives an indication of the electrical loading on the AC bus. The current measurements on each phase are compared by the GCU and if there is a difference of more than 45 amperes over a period of 35 milliseconds, the GCU detects a Differential Protection (DP) event and opens the GLC.

Once a DP event has been detected, the fault can be isolated into one of two zones. Zone 1 comprises the feeder cables between the generator and the GLC. Zone 2 is the network downstream of the GLC. To isolate the fault to one of the zones, the PR relay is briefly de-energised, causing the GLC to open. The on-side BTC is also maintained open. If the differential current then disappears, the fault has been isolated to Zone 2 and the BTC is locked out to prevent the other network from being connected to the fault. If the fault persists for an additional 85 milliseconds, the fault has been isolated to Zone 1 and the on-side BTC will be allowed to close. DP fault information is written to the GCU Non-Volatile Memory (NVM) at the end of this checking sequence. If the fault is in either of the two zones, the PR relay trips, removing power from the GLC, causing it to open and illuminating the fault legend on the corresponding generator control switch. A DP fault in Zone 1 is denoted as a DP1 fault and a DP fault in Zone 2 as a DP2 fault.

1.6.5.7 False DP2 detections

In-service experience on aircraft with the 'Classic' EPGS configuration has shown that false DP2 trips can occur. Investigation of such events has shown that an intermittent defect in Zone 1 (upstream of the GLC) can cause the GCU to record a false DP2 event, causing the loss of the associated AC bus and those busses fed by it. Airbus advise that possible sources of a spurious DP2 event might include an intermittent short in an IDG or in the IDG feeder cables between the IDG and the GLC, or an intermittent fault in a current transformer.

In September 2006, Airbus issued Technical Follow Up (TFU) No 24.22.00.005, advising operators of A320 family aircraft of this problem. This document highlights that the loss of AC BUS 1 will result in the loss of the captains PFD, ND and the Upper ECAM and in some cases, for reasons unknown, can cause the loss of the co-pilot's PFD and ND. It includes a reminder that all electrical systems may normally be recovered by manually selecting the AC ESS FEED push button to 'ALTN' as per the ECAM procedure.

The TFU also states that Airbus is investigating the feasibility of automatic reconfiguration of the AC and DC ESS busses if AC BUS 1 is lost and also improving the DP detection logic within the GCU, to address the issue of false DP2 trips. To date, only aircraft with the 'Classic' EPGS configuration have experienced occurrences of false DP2 trips.

1.6.6 Component testing

Various components associated with the control and switching of the aircraft's electrical networks and the Electronic Instrument System were removed for examination and testing.

The three Display Management Computers (DMC1, 2 and 3), the No 2 System Data Acquisition Concentrator and Flight Warning Computer were removed for interrogation of the fault memory. The results of this proved inconclusive.

The No 1 Generator Control Unit, part number 740120C, serial number 6520, was sent to the manufacturer for the NVM to be downloaded. No faults were found that related to the incident.

The No 1 and No 2 Auxiliary Relays, GLC 1, (which controls the switching of power from the No 1 (left) generator to its on-side electrical network) and the AC Essential Feed contactor were tested and strip examined. The tests were satisfactory and no evidence was found of contamination, arcing, electrical welding of the contacts, or any other defect.

1.6.7 Electronic Instrument System

1.6.7.1 Introduction

A320 family aircraft are equipped with an Electronic Instrument System (EIS), incorporating six identical display units (Figure 3). These include the captain's and co-pilot's Primary Flight Displays and Navigation Displays, the Engine/Warning display and the Systems display. The latter two are commonly referred to as the upper and lower ECAM displays.

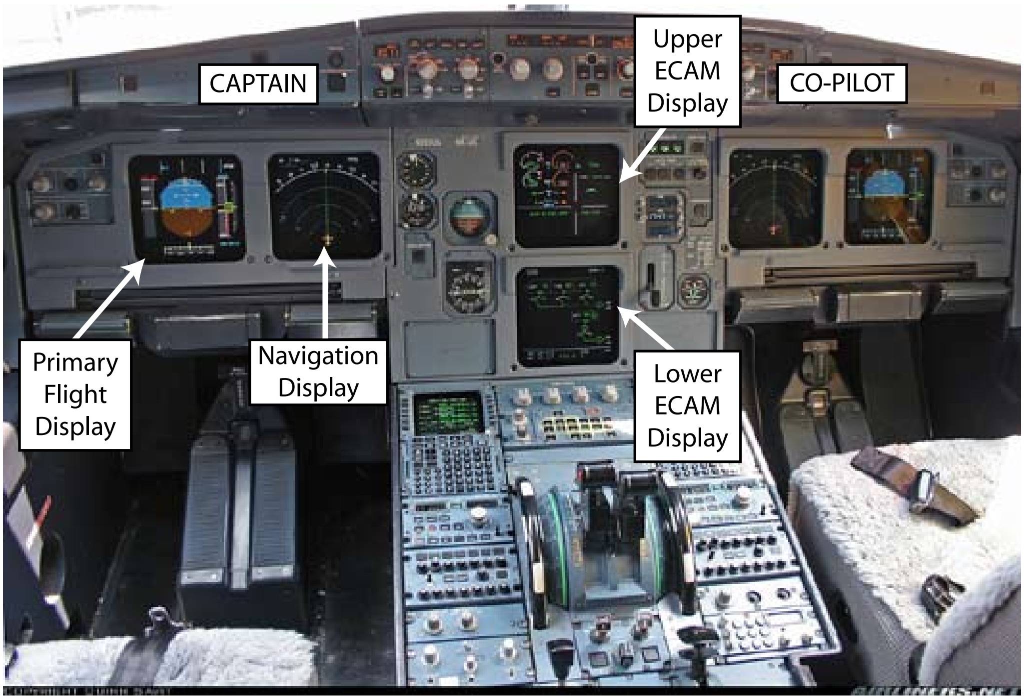

Figure 3

A320 family Electronic Instrument System Layout

There are two configurations of EIS, denoted EIS1 and EIS2. The EIS1 configuration, as installed on G-EUOB, employs Cathode-Ray Tube (CRT) type displays, whereas the later EIS2 configuration utilises liquid crystal displays. There are significant software and hardware differences between the two configurations.

1.6.7.2 Electronic Flight Instrument System (EFIS)

The EFIS displays are comprised of the captain's and co-pilot's Primary Flight Displays and Navigation Displays. The PFDs present the pilots with the basic information required to fly the aircraft, such as aircraft attitude, airspeed, vertical speed and altitude. They also display flight path trajectory deviation and autopilot flight mode selection information. The NDs present navigational and weather radar information.

1.6.7.3 Electronic Centralised Aircraft Monitoring system

The upper ECAM display presents engine primary data, wing flap/slat positional data and ECAM warning messages and memos. Following an aircraft systems failure, the affected system(s) are automatically listed on the lower part of the upper ECAM display, together with checklist actions to be carried out by the crew (Figure 4).

Figure 4

Upper ECAM Display showing sample failure messages and checklist actions

The lower ECAM display normally presents synoptic diagrams showing the status of the aircraft's systems. This information is displayed on various system pages, which change automatically according to the flight phase. A specific system page may be called up manually, by selection of the appropriate button on the ECAM control panel, or may appear automatically following an aircraft system failure.

If the upper ECAM display fails, the information normally presented on it is automatically transferred on to the lower ECAM display, replacing the system/status information. In this case a specific system page is accessed by one of several different methods, depending on the reason for the failure.

The lower part of either ECAM screen can only display a limited number of lines of text. In the event of a system failure, each ECAM warning message/memo item must be read by the crew, actioned if required and then cleared by pressing the 'CLR' button on the ECAM control panel. As items are cleared, the list scrolls upwards on the screen and further messages appear, until the end of the list is reached.

If the lower ECAM display unit fails, the information on it can be displayed on either the captain's or the co-pilot's navigation display unit, by manual switching.

The representation of the failures on the ECAM display does not necessarily allow a crew an understanding of the primary failure. ECAM is the tool through which the crew can take corrective action in the event of system failures. The crew may be able to obtain more information about the nature of a failure by consulting the Flight Crew Operating Manual (FCOM) but in this case, because it was not a known failure case, this would not have assisted.

1.6.7.4 Minimum Equipment List

The Master Minimum Equipment List (MMEL) produced by the manufacturer is the basis on which the operator's Minimum Equipment List (MEL) is compiled. The MEL allows aircraft to be operated for limited periods of time with certain non-critical items of equipment inoperative. The Airbus A318/A319/A320/A321 MMEL states, in Chapter 31, 'INDICATING/RECORDING SYSTEMS', that of the six EIS display units, five, which must include the upper ECAM display unit, must be serviceable. A display unit is a Category 'C' item, which means that it must be repaired within ten consecutive days.

It is therefore permissible for an aircraft to be dispatched with the lower ECAM display inoperative. In this incident, as well as in the previous cases referred to in the Airbus TFU discussed in paragraph 1.6.5.7, the lower ECAM display was the only one left available to the crew.

Chapter 34 of the MMEL states that the standby attitude indicator must be serviceable.

1.6.7.5 EIS Display Unit description

This aircraft was equipped with six EIS CRT Display Units (DUs) which are identical and interchangeable. The DUs generate the colour images to be presented on the EFIS and ECAM displays. Each DU has a rotary control switch, which provides manual on/off and brightness control. The captain's PFD and ND on/off/brightness control switches share a common earthing point; the same is also true for the co-pilot's displays. The brightness of the DUs is also controlled automatically according to the ambient light level sensed by sensors mounted on the front of each DU. Other configurations of the A320 family aircraft have EIS 2 displays which are Liquid Crystal Displays (LCD).

1.6.7.6 Display Management Computers

There are three identical Display Management Computers, identified as DMC1, 2 and 3. The DMCs acquire and process the signals received from sensors and other computers to generate the graphics signals and produce the images on the display units. Each DMC is able to drive simultaneously one PFD, one ND and one ECAM display unit. The three display channels are independent, with the exception that they share a common Random Access Memory module, located on the circuit board for the PFD channel.

In the normal configuration, DMC1 drives the captain's PFD, ND and the upper ECAM display and DMC2 drives the co-pilot's PFD, ND and the lower ECAM display. DMC3 is available as a backup. If DMC1 or 2 should fail, DMC3 can be manually selected to replace the failed unit. Failure of one or more channels within a DMC will cause a diagonal line to appear on the corresponding display unit(s).

1.6.7.7 EIS power supplies

The display units require AC power to drive the displays and DC power for display switching. The captain's PFD and the upper ECAM display are powered from the AC ESS bus and the captain's ND from the AC ESS SHED bus. The co-pilot's PFD, ND and the lower ECAM displays are powered from AC BUS 2. The power supplies for the upper and lower ECAM displays are similarly segregated, with the upper ECAM display receiving power from the AC ESS bus and the lower display from AC BUS 2.

DMC1 is powered from the AC ESS bus and DMC2 from AC BUS 2. DMC3 is normally powered from AC BUS 1, however if DMC3 is selected to feed the captain's instruments and AC BUS 1 fails, the power supply for DMC3 will automatically switch to the AC ESS bus.

The normal EIS power supply configuration is shown in Figure 5. The expected effect on the EIS displays due to an AC BUS 1 failure is shown in Figure 6. Figure 7 shows the EIS power supply configuration after selection of the AC ESS FEED switch to 'ALTN'.

1.6.7.8 ECAM procedures for failure management

It is believed that the items displayed on the first 'page' of the lower ECAM display following the incident would have been as follows:

AUTOFLIGHT AP OFF

ENG 1 EPR MODE FAULT

-ENG 1 N_1 MODE..........ON

-ENG 2 N_1 MODE..........ON

-MAN THRUST..............ADJUST

ENG 2 EIU FAULT

ENG 1 AC FADEC SUPPLY

The action which restored most of the affected systems, including the flight instruments, was:

ELEC AC ESS BUS FAULT
-AC ESS FEED...........................ALTN

This ECAM action was the ninth or tenth item on the list and was not initially visible; it would only have appeared on the lower ECAM display after some of the preceding actions had been cleared. The co-pilot was hampered in carrying out the ECAM actions by the lack of lighting on the panels, with the result that the AC ESS FEED push button switch was selected to 'ALTN' some 90 seconds after the initial failure.

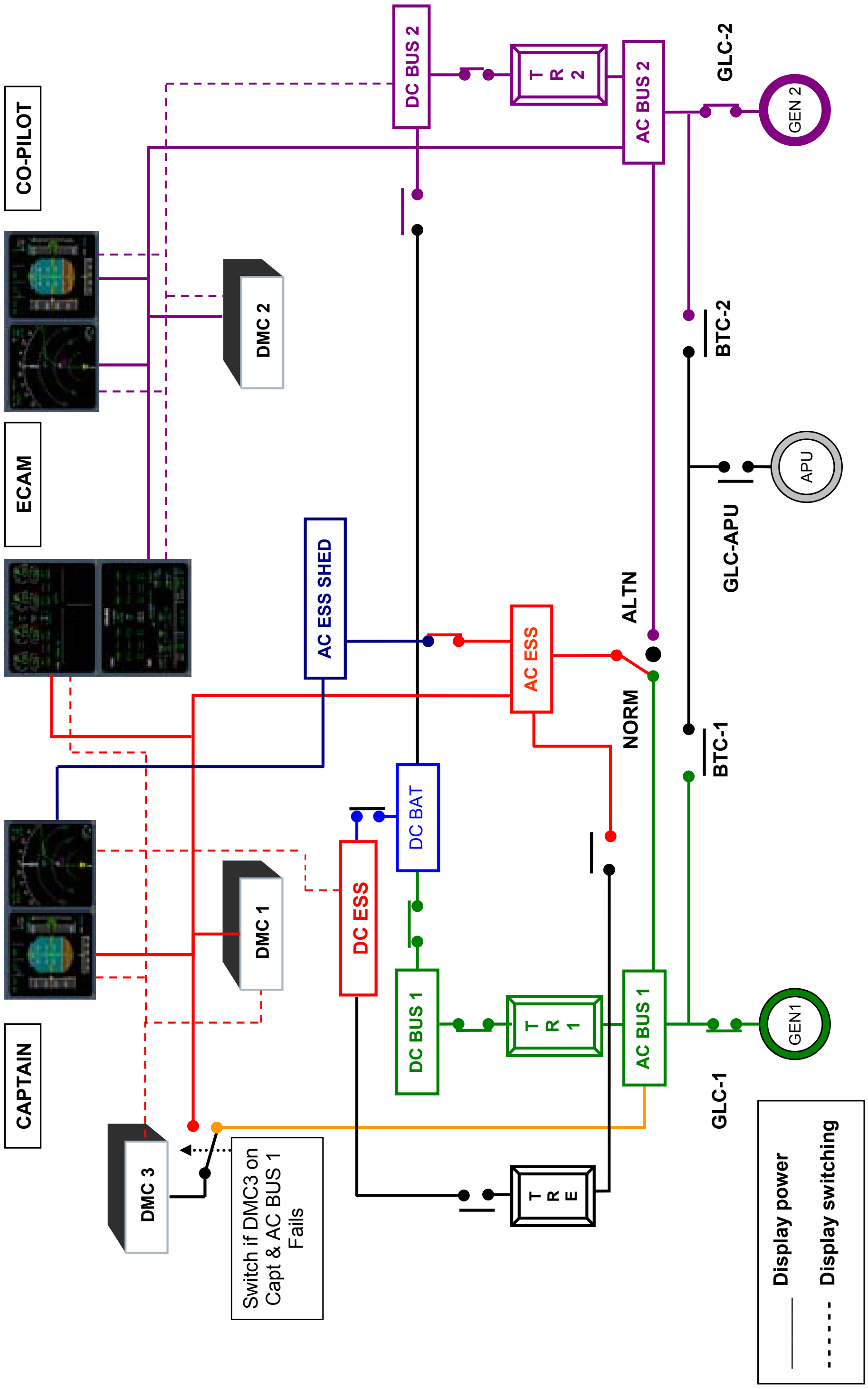

Figure 5

EIS Normal Power Supply Configuration

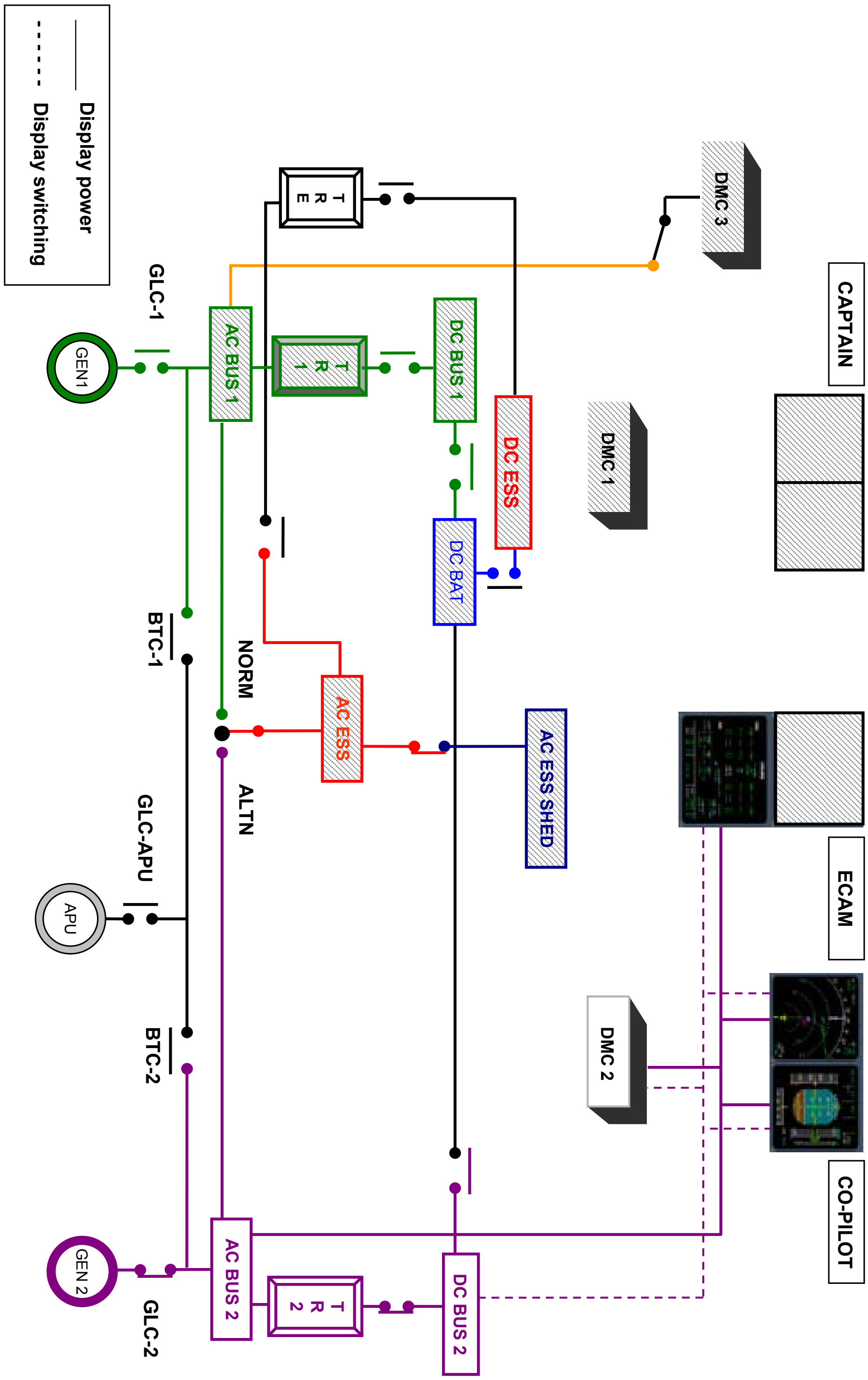

Figure 6

EIS Effects following AC BUS 1 Failure

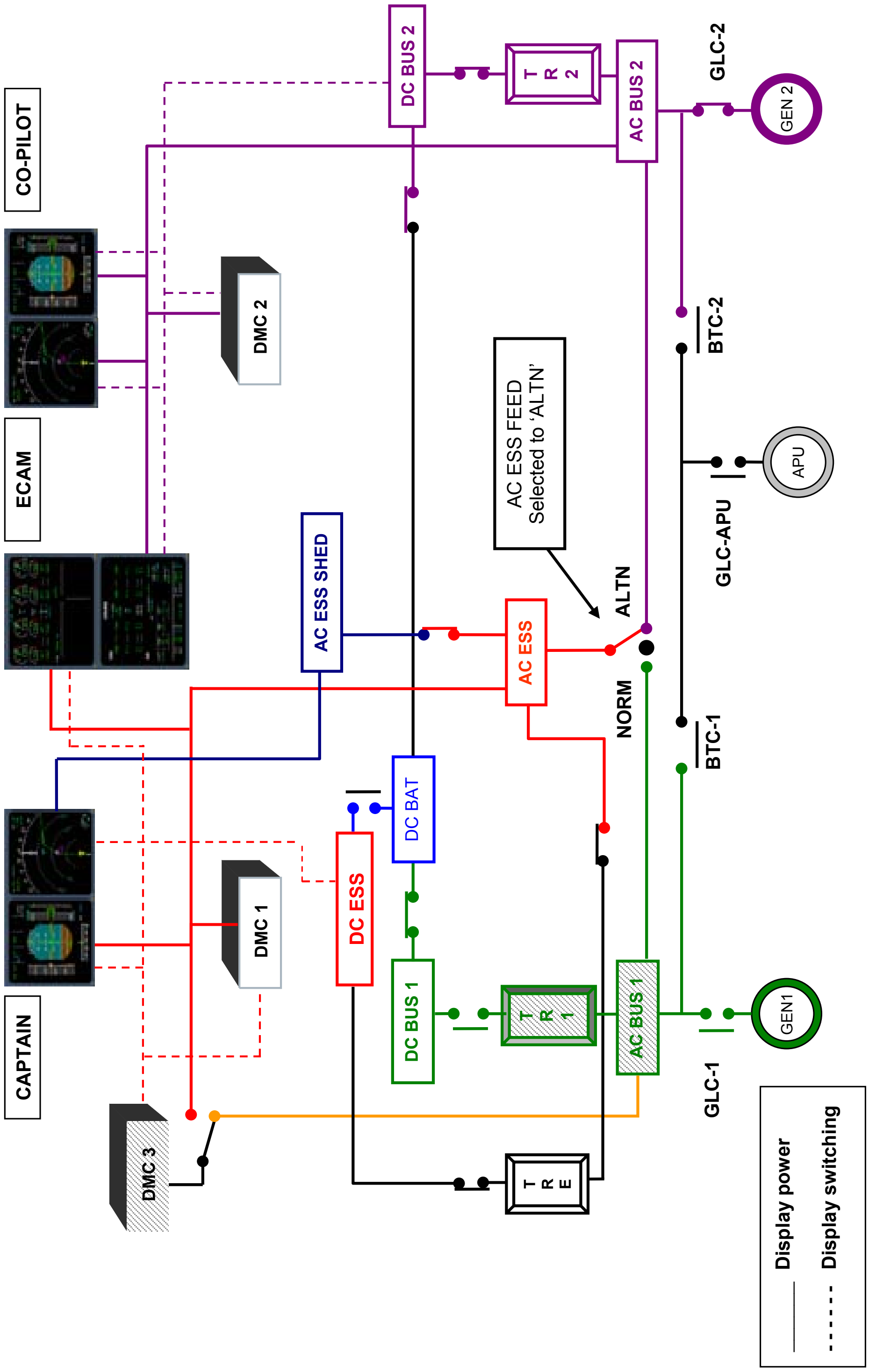

Figure 7

EIS Power Supplies - AC ESS FEED selected to 'ALTN'

1.6.8 Standby instruments

If the captain's and co-pilot's primary flight instruments are unavailable, the aircraft may be flown by reference to the standby instruments. These include the electric standby horizon, the standby airspeed indicator, standby altimeter and compass. They may be of either the 'mechanical' type, such as those installed on G-EUOB, or of an electronic display format, known as the Integrated Standby Instrument System (ISIS), introduced by Airbus Modification No 28658. The mechanical standby compass is mounted on the centre windscreen pillar in a retractable housing, which must be extended manually to expose the compass.

Due to customer options available from the manufacturer, the standby horizon may have either a single or dual power supplies. For aircraft without the ISIS wiring provision, the standby horizon is powered by the DC ESS bus only. The DC ESS bus is normally fed from AC BUS 1. If either of these should fail, the standby horizon will lose power and become unusable after about five minutes. Airbus advise that, as of mid-April 2006, 1,664 A320 family aircraft did not have the ISIS wiring configuration.

On aircraft with the ISIS wiring configuration, provision is made for a dual power supply to the standby instruments. In this case, if the normal DC ESS bus supply is lost and the airspeed is above 50 kt, the standby horizon will be powered from the HOT BUS 1 battery bus and will continue to operate.

Some aircraft, including G-EUOB, were manufactured with the ISIS wiring installed, but were fitted with conventional electro-mechanical standby instruments in accordance with customer preference. The standby horizons on these aircraft therefore have a dual power supply and will remain powered if the DC ESS bus supply is lost.

In AAIB Special Bulletin S2/2005, issued on 25 November 2005, it was reported that the standby horizon on G-EUOB would not have remained powered. This statement is incorrect and was based on information contained in the FCOM for G-EUOB, which implied that the standby horizon had the single power supply configuration. The FCOM has since been amended by Airbus to reflect the two configurations of power supply.

1.6.9 VHF radio and ATC transponder

1.6.9.1 VHF radio

The VHF radio communication system comprises the Audio Control Panels (ACP), Audio Management Units (AMU), the transceivers and the Radio Management Panels (RMP). The ACPs enable the crew to select the radio channel and adjust the volume. There are three identical ACPs, one each for the captain and co-pilot, located on the centre console and a third, mounted on the overhead panel, behind the co-pilot's station. The three RMPs, which are adjacent to the ACPs, enable the crew to select the desired radio frequency for communication and also contain the controls for the back-up radio navigation system. The radio systems are designated No 1, 2 and 3, for the captain, co-pilot and observer's systems, respectively.

If ACP 1 or ACP 2 fail, the crewmember can switch to the ACP 3, by selecting the AUDIO SWITCHING selector (located on the overhead panel) to either 'CAPT 3' or 'F/O 3'. Audio selections must be made on ACP 3, but frequency selections are made on the RMPs as normal.

ACP 1, ACP 2, RMP 1 and VHF 1 transceiver are powered from the DC ESS bus. The VHF 2 transceiver and RMP 2 are powered from DC BUS 2. The VHF 3 transceiver, ACP 3 and RMP 3 receive power from DC BUS 1.

1.6.9.2 ATC transponder

The aircraft was equipped with two independent transponder channels, designated ATC 1 and ATC 2. When interrogated by ATC radar, the transponder transmits data which can be decoded by ATC radar to display specific information on the aircraft, including its altitude, on the radar screen.

The ATC transponder provides data to the Traffic Alert and Collision Avoidance System (TCAS). If the selected transponder system fails the crew must manually select the other system on the ATC control panel located on the centre pedestal. Loss of the transponder also causes the TCAS to be inoperative.

ATC 1 is powered from the AC ESS SHED BUS and ATC 2 from AC BUS 2. TCAS is powered from AC BUS 1.

1.6.10 Cockpit and instrument lighting

The cockpit is provided with various sources of background and specific illumination (Figure 8). The instruments (including the standby instruments) and the panels in the cockpit (apart from the EIS display units) are provided with integral lighting, which is adjustable in brightness. The power for this lighting is supplied by AC BUS 1, with the exception of the standby compass integral lighting, which is powered from the DC ESS bus.

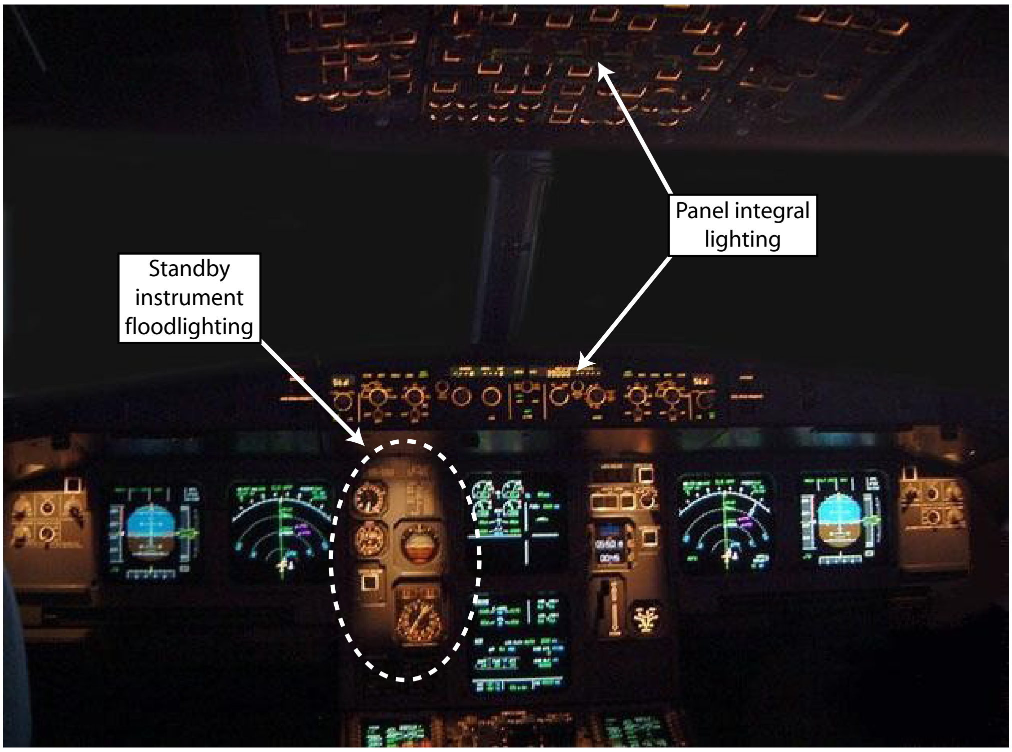

Figure 8

View of instruments by night showing lighting and EIS displays

The centre instrument panel can be floodlit by two lights mounted under the glareshield. The left floodlight illuminates the standby instruments and is powered by the DC ESS bus, the right is powered by DC BUS 1. The centre pedestal between the two pilots is illuminated by a floodlight in the overhead panel, which is powered by DC BUS 1. The floodlight illumination, by design, has a sharp cut off and therefore areas outside the direct pool of light remain dark.

General cockpit illumination is provided by two 'dome' lights, located in the ceiling behind the pilot and co-pilot stations. A switch on the overhead panel allows the dome light to be set to bright, dim, or off. The left dome light is powered from the DC SVCE bus and the right from the DC ESS bus.

Each pilot station has a lighted map and chart holder and additional lighting is provided for the side consoles and at floor level, however none of these lights provide illumination for the instruments. The power sources for these lights are DC BUS 1 for the captain's side and DC BUS 2 for the co-pilot's side.

Hand-held torches are available at each pilot station for use in an emergency.

1.6.11 Centralised Fault Display System (CFDS)

The main function of the CFDS is to acquire and store data on aircraft systems faults. The recorded faults and associated messages are labelled according to the phase of flight in which they occurred, and the time of occurrence. At the end of a flight, the CFDS generates a Post-Flight Report (PFR), containing a list of recorded system faults, together with the corresponding ECAM fault messages which occurred during the flight. This primarily serves as a troubleshooting aid to maintenance personnel.

The CFDS is powered by DC BUS 1. As DC BUS 1 was lost for approximately five seconds following the loss of AC BUS 1, the CFDS was not capable of recording any fault messages during this period. The PFR for the incident therefore only recorded consequential failures and provided no evidence relating to the cause of the incident.

The PFR showed the following systems, which are powered from the left electrical network, as being inoperative during the incident:

> TCAS, EGPWS, FMC1, FCDC1 DME1, SDAC1, PHC1, WHC1, BMC1, DMC1 and DMC3, pressure transducer 8HA1, FWC1, ADF1, FAC1, RA1, FQI1, SFCC1, CFDIU1 and RADAR1. These faults are consistent with the loss of the No 1 autopilot, autothrust, the captain's EFIS displays, the upper ECAM display and other failure symptoms reported by the crew.

The PFR also showed that the following systems, either powered from the right electrical network or on the right side of the aircraft, were also affected: avionics cooling extractor fan 18HQ (this is powered from the left network, but the control function is powered from the DC ESS bus), EIU2 (Channel A is powered by the DC ESS bus), EEC2 (this recorded a fault, associated with the loss of EIU2).

1.6.12 Hydraulic system

The blue hydraulic system is nominally pressurised by an electric pump powered from AC BUS 1. Of the systems this supplies, the only ones without an alternative source of hydraulic power are the No 3 spoilers, left and right.

1.7 Meteorological information

The 1850 hrs Meteorological Terminal Area Report (METAR) issued for London Heathrow was: Surface wind from 260º at 7 kt, CAVOK[7], temperature 13°C, dew point 10°C and QNH[8] 1003 mb.

An aftercast of the weather situation in the London area showed that around the time of the incident overhead Clacton there were isolated convective clouds with tops up to 10,000 ft and higher cirrus cloud in thin layers at around 20,000 and 28,000 ft. Otherwise there was mainly dry, clear air. The temperature at FL200 was minus 25°C, the dew point was minus 43°C and the wind was from 250° at 40 kt. There was no significant weather report (SIGMET) issued for the area in the period.

The forecast for Budapest valid from 1900 hrs 22 October 2005 to 0400 hrs 23 October 2005, which was received onboard the aircraft before departure, was as follows:

> '*Surface wind variable 2 kt, visibility 3,000 m, mist, broken cloud at 500 ft, becoming between 1900 hrs and 2100 hrs, visibility 1,500 m, fog patches, mist, overcast cloud at 200 ft. Temporarily between 2100 hrs and 0400 hrs visibility 500 m, fog, drizzle, overcast cloud at 100 ft.*'

The 1930 hrs METAR issued for Budapest was: surface wind variable 3 kt, visibility 1,800 m, mist. Fog patches, broken cloud at 400 ft, temperature 12°C, dew point 12°C and QNH 1015 mb. The 2200 hrs METAR was similar except that the cloud base had lowered to 300 ft.

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7 CAVOK is a term meaning: visibility equal to or greater that 10 km, no cumulonimbus cloud, no cloud below 5,000 ft or highest Minimum Safe Altitude, whichever is greater, and no weather significant to aviation.

8 In an International Standard Atmosphere, the QNH is the equivalent Mean Sea Level pressure as calculated by Air Traffic Control.

1.8 Aids to navigation

Not applicable.

1.9 Communications

1.9.1 Air Traffic Control

The transmissions between G-EUOB and ATC were recorded and were reviewed during the investigation. The aircraft was using the call sign 'Speedbird 870' and at the time of the incident it was under the control of Lambourne Terminal Control (LAM TC) on frequency 121.225 MHz.

At 1926 hours the LAM TC controller gave Speedbird 870 a frequency change to the next sector, but the aircraft did not respond. For the next 90 seconds the controller made further attempts to call the aircraft, including a blind transmission to ask the aircraft to squawk 'IDENT' on the ATC transponder if transmissions were being received. The controller noted that the transponder secondary coded information for the aircraft was missing from his radar screen. He contacted another aircraft on the same frequency and asked him to attempt to contact Speedbird 870. The second aircraft tried to make contact as requested after which, and co-incident with the restoration of power to the radio, Speedbird 870 started to receive radio transmissions again.

Once communication was restored, Speedbird 870 advised ATC that the aircraft had suffered an electrical failure and declared a 'PAN'. The crew were passed a heading and then, at their request, a direct route to the hold 'BRASO' with a holding pattern at FL230. The aircraft remained in the hold for some 40 minutes, during which time ATC made occasional transmissions to check that all was well.

Speedbird 870 then advised ATC that they wished to continue en-route to Budapest, and, following a brief discussion about the event between the commander and the controller, the aircraft was transferred to the next ATC sector frequency.

1.9.2 Operator's Maintenance Control frequency

The commander contacted the operator's Maintrol facility for technical advice, on a VHF frequency which is shared with several other operators. A recording of these communications was available for the investigation. The frequency was in use by a number of other aircraft and ground stations at the time and as a result, the communications suffered from frequent interruptions and was generally of poor quality.

1.9.3 Flight interphone

The crew were wearing noise cancelling headsets and used the flight interphone for communication between themselves. The intercom was inoperative during the incident, rendering communication between the crew members more difficult.

1.10 Aerodrome information

Not applicable.

1.11 Flight recorders

1.11.1 Data sources

The aircraft had a Cockpit Voice Recorder (CVR), a Flight Data Recorder (FDR) and a Digital AIDS Recorder (DAR – AIDS being an acronym for Aircraft Integrated Data System). The two hour CVR and 25 hour FDR recordings were overwritten by the time the AAIB were notified of the incident. The DAR stored a number of different, longer duration, recordings. One of these was data in the same format as the FDR, however, this recording did not cover the incident. The DAR also recorded data in an operator definable format and these data did cover the event period. This is the data used for this investigation and, for brevity, is referred to as the DAR data.

The DAR data was sourced from different units that act as data concentrators for many aircraft systems. Some of these systems lost power during the event and so all data associated with those devices were lost. Some of the concentrators remained powered but some of their data sources lost power. The DAR data itself has no quality indicators so it is only through analysis of the way in which a parameter is sampled that conclusions can be drawn as to whether a recorded status is valid or is a possible indication of an invalid parameter.

The DAR data includes a vast array of parameters, however, the configuration control of these recordings is not required to be robust and so the data is not subject to the same control standards as the mandatory recordings of the FDR. Ground tests showed that many of the parameters become invalid when power is lost from certain electrical busses. This means that some recorded data is unreliable during the electrical power loss event but accurate before and after the event.

1.11.2 Recordings

The following description of the flight is derived from DAR data, all times are referenced to UTC. Figures 9 and 10 focus on the event period.

The aircraft departed Heathrow airport at 1918 hrs on a heading of 272ºM. Shortly after takeoff, autothrust and Autopilot 1 were engaged and the aircraft turned north and then east in the climb. A steady climb was maintained with selected altitudes stepping up ahead of the aircraft.

At 1926 hrs the No 1 generator load fell to zero. The recorded data does not indicate the cause of the loss of electrical power. At the time, the aircraft was climbing through FL190 at 2,100 feet per minute (fpm) with a Computed Air Speed (CAS) of 310 kt and a steady heading of 080ºM. The wings were level, Autopilot 1 was engaged and autothrust was engaged. The last altitude selection prior to the power failure was FL230.

At this point many of the parameters were recorded as active or inactive when they were in fact invalid, which is not a recorded state. Some parameters that are progressive during the flight, such as aircraft position, were updated smoothly throughout the recording showing that the recording was uninterrupted.

No reasonable parameters were available to indicate cockpit display status, autopilot status or sidestick status during the initial period of electrical power loss.

The loss of Enhanced Ground Proximity Warning System (EGPWS) data, amongst others, indicates a loss of power to the AC BUS 1. The continued operation of the DAR shows that AC BUS 2 remained powered. The AC ESS SHED bus was reliably recorded as failed. The AC ESS bus parameter showed one sample of definite loss of power before becoming an unreliable parameter, however, parameter failures of systems powered by AC ESS point to the loss of this bus for the same period as the AC ESS SHED bus. Other parameters directly relating to power proved unreliable during this period.

The DC BUS 1 showed a temporary failure for between 4 and 12 seconds (this parameter is sampled every four seconds). The continued good FMC2 and accelerometer data indicate that DC BUS 2 remained healthy throughout. Loss of FMC1 data points to the loss of power on the DC ESS SHED bus. Flap parameters reported by the Slat Flap Control Computer (SFCC) 1 became invalid indicating that the DC ESS bus lost power.

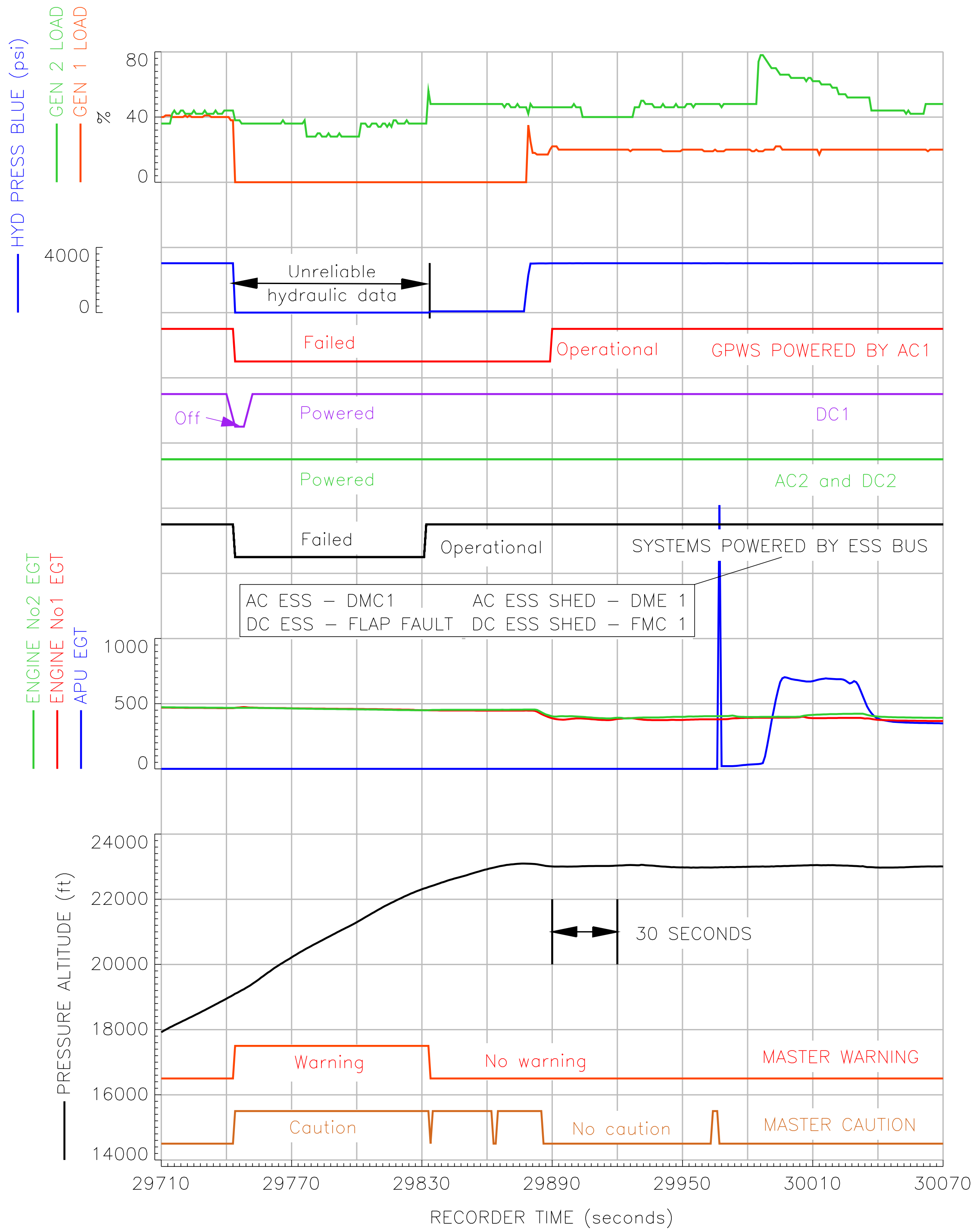

Figure 9

DAR derived data showing the power available on the aircraft.
Note: the yellow and green hydraulic systems were unaffected.

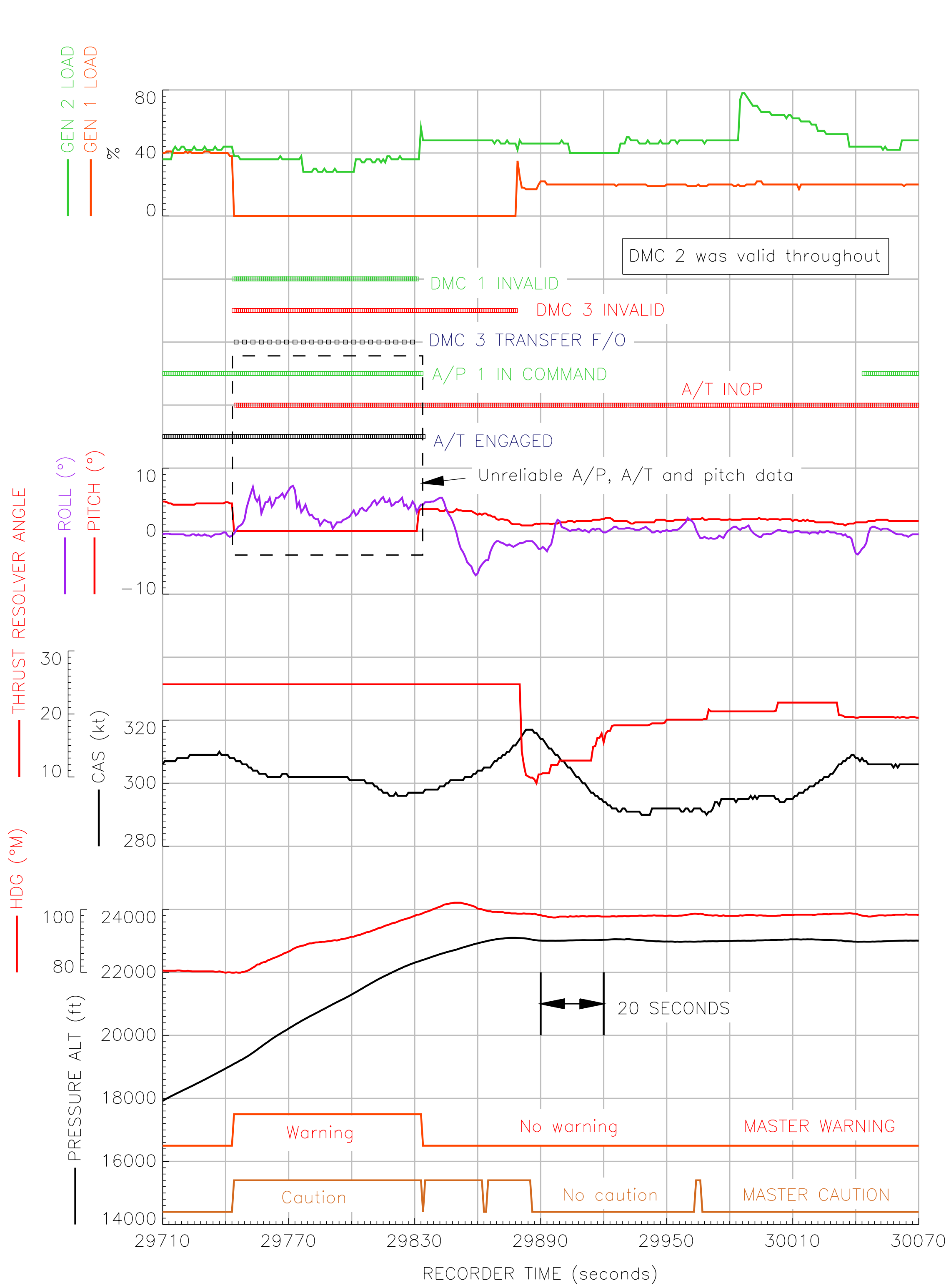

Figure 10

DAR derived data showing the parameters relating to the control of the aircraft.

DMC1 and DMC3 were no longer powered; however DMC2 remained operational.

The available data did not allow determination of which DMC was supplying the co-pilot's displays for the duration of the electrical power loss. Those display parameters which should have been reliable under these failure indications, indicated that the co-pilot's PFD was operational, the lower ECAM was operational, the ECAM/ND transfer switching was inactive and the co-pilot PFD/ND switching was inactive. No reliable data was recorded to indicate whether the PFDs, NDs and ECAM displays were actually blank or not.

In the 10 seconds following the loss of power, the aircraft rolled right wing down to a peak of 7º. The roll then recovered slightly, peaked at 7º again, reduced to near wings level and then increased again to about 5º right wing down.

During the period of electrical power loss the aircraft pitch and power settings did not change appreciably. The aircraft continued to climb, though the rate of climb and the airspeed slowly reduced.

Ninety seconds after the initial loss of power, there was a step increase in the load on the No 2 generator. The No 1 generator maintained a zero load status. Many of the recorded parameters that were previously unreasonable became valid. The AC and DC ESS SHED busses became active. DMC1 became valid and the display parameters indicated normal operation. DMC3 remained invalid: whilst not transferred to the captain's displays, DMC3 is powered by AC BUS 1. The EGPWS, also powered by AC BUS 1, also remained inactive.

On restoration of power to the units supplying information to the recorder, the data showed inputs from the captain's sidestick, the autopilot was not engaged and the autothrust system was inoperative. The engines had changed from EPR to N_1 mode. The CAS had reduced from 311 kt to 296 kt.

For 10 seconds after the restoration of power the aircraft continued with the right wing 5º down. Over the next 15 seconds the roll angle changed to 7º left wing down. Subsequently the roll angle reduced and showed only small changes until controlled turns were initiated. The aircraft heading had changed by 22 degrees during the electrical power loss and subsequent roll recovery. The rate of climb reduced smoothly after the restoration of power, in association with an increase in speed.

Two minutes and 15 seconds after the initial loss of power, the No 1 generator was recorded as taking up load, indicating that AC BUS 1 became active.

The EGPWS parameters became valid a short period after this, indicating that AC BUS 1 became powered. At about this time the aircraft finished levelling off at FL230 and the CAS peaked at just less than 320 kt, followed by a steady speed reduction back to the speed before the incident occurred. No further electrical anomalies were recorded.

One and a half minutes after the restoration of the No 1 generator, the APU was started, accompanied by a brief master caution. It did not supply any electrical power during the flight. After a further one minute and 15 seconds the autopilot was re-engaged and remained so until just prior to landing. Autothrust was not re-instated.

At 1934 hrs, approximately 6 minutes after restoring the No 1 generator, the aircraft turned to heading 290ºM and entered a holding pattern at FL230. Whilst in the hold there was a brief master caution in conjunction with temporary engine mode selection change from N_1 to EPR. At 2001 hrs the APU was shut down. At 2012 hrs the aircraft headed east, climbed to FL330 and continued the flight with no problems apparent from the recorded data. The aircraft landed at 2201 hrs; the recorded data confirmed that the autopilot was disconnected just prior to landing and that during the landing, the co-pilot was the handling pilot.

Data relating to the hydraulic pressures of the yellow, green and blue systems were invalid during the first 90 second period of electrical power loss, before AC Essential power was restored. The data reliably showed that the yellow and green hydraulic systems did not have a low pressure indication throughout the event. However, the blue hydraulic system showed a valid low pressure condition from eight seconds after the initial loss of power. When the AC Essential power was restored, the blue hydraulic pressure was recorded as 76 pounds per square inch (psi) and remained so until the No 1 generator was brought back on line. For most of the period between the restoration of the AC ESS bus and the No 1 generator coming back on line, the blue low pressure parameter indicated a low pressure problem with the exception of two brief periods that coincide with rudder movement.

The parameters relating to the Ram Air Turbine (RAT) were invalid during the event but there is no indication of RAT deployment immediately prior to or after the event.

1.12 Wreckage and impact information

Not applicable.

1.13 Medical and pathological information

Not applicable.

1.14 Fire

There was no fire.

1.15 Survival aspects

Not applicable.

1.16 Tests and research

1.16.1 Flight deck effects investigation

In order to establish the degree to which the operation of the aircraft would have been affected, a trial was carried out on G-EUOB in order to reproduce, as far as possible, the symptoms reported during the incident. This test was performed at London Heathrow on 8 March 2006, with the assistance of Airbus.

The trial was performed at night, with the aircraft on the ground, engines running, the No 1 and No 2 generators on line and the cockpit lighting adjusted to a typical setting for a night takeoff and climb (instrument integral lighting on a low brightness setting, floodlights off and the dome light selected to DIM). The electrical system was reconfigured to remove power from the AC ESS and DC ESS busses (by selecting the BUS TIE switch to 'OFF', to inhibit the automatic electrical reconfiguration and then selecting the GEN 1 switch to 'OFF'). The circuit breakers for the co-pilot's PFD and ND were also pulled, to simulate the reported blanking of these screens, as the actual cause of these screens blanking was not known and could not be reproduced.

When the GEN 1 switch was selected to 'OFF', the pilot's PFD, ND and the upper ECAM screen became blank, in addition to the co-pilot's PFD and ND which were already blank. The cockpit became very dark due to the loss of all of the instrument and panel integral lighting, including the standby instrument integral lighting. The co-pilot's dome light went out, leaving the captain's dome light as the only available source of general illumination. This provided sufficient light for the standby instruments to be visible, albeit with some difficulty. When the dome light was switched off, the standby instruments became unreadable due to lack of light. The centre instrument panel floodlight, which can be used to illuminate the standby instruments (Figure 8, page 26), was no longer available.

1.16.2 Airbus 'Iron bird' tests

The A320 'iron bird' is an integrated ground-based rig used to test the performance of the aircraft's major systems, such as the flying controls, hydraulics and electrical systems.

Various tests were performed by Airbus on the A320 iron bird, to determine whether different faults introduced into the left electrical network could affect the right network and in particular, whether the co-pilot's PFD and ND displays could be affected. The results of these tests were negative and in no case were the co-pilot's displays affected.

1.16.3 Display unit testing

Bench tests on A320 family CRT EIS display units were performed by Airbus to establish how the units behaved in response to voltage variations. The results of these tests showed that the displays were relatively insensitive to voltage variations and operated satisfactorily at voltages as low as 71 volts AC.

Further tests revealed that introducing a resistance to ground on the DMC3/2 transfer discrete wire can result in partial DMC3/2 transfer, causing the co-pilot's display units to no longer be driven by DMC2 and to switch to DMC3. This is repeatable with specific resistances causing the transfer of specific displays; one such resistance causes the lower ECAM to still be driven by DMC2 but the co-pilot's ND and PFD are transferred to DMC3. However, a link between this failure mode and the electrical power loss has not been established.

1.17 Organisational and management information

1.17.1 UK Mandatory Occurrence Reporting scheme

The purpose of the UK Mandatory Occurrence Reporting scheme is to improve flight safety through the reporting and dissemination of knowledge of safety related occurrences so that other persons and organisations may learn from them. In order to secure free and uninhibited reporting, the confidentially of the reporter is maintained where possible. The scheme defines the categories of persons who are required to make reports and also encourages others to make voluntary reports. The scheme requires that copies of the MORs are sent to the

UK Civil Aviation Authority for review. The CAA regularly provides the AAIB with a summary of the MORs and it was through this channel that the AAIB became aware of this incident.

1.17.2 Operator's Air Safety Reporting procedures

In order to comply with the requirements of the UK MOR scheme, the airline had an established procedure for reporting of incidents affecting flight safety. Staff were encouraged to report mandatory and other safety related incidents through the Safety Management System.

One means of capturing such information is the Air Safety Report form, copies of which are available on board the aircraft. The instructions for completing the form are printed on the reverse side. These include the postal address for the Flight Operations Safety Department (FOSD), to which the original must be sent and fax numbers to which copies must be sent. One fax number is for the airline's FOSD at London Heathrow and the other is for the World Network Services (WNS) department located in Mumbai, India. The latter is responsible for entering the details of the incident on to the airline's electronic safety management database, known as 'eBASIS'. The incidents are reviewed by safety officers in the FOSD and allocated to the appropriate departments within the airline for investigation. The safety actions taken are monitored by the FOSD and the incident is recorded as closed on 'eBASIS' after appropriate safety actions have been taken to prevent recurrence.

The original copy of the G-EUOB ASR form was sent by post from Budapest and was received by the FOSD four days later. The faxed copies were reportedly sent, but these were never received by the FOSD or the WNS department in Mumbai. The reasons for this could not be established.

1.17.3 Aircraft technical log

The aircraft technical log contains operational information and information regarding the status of the aircraft's airworthiness, including any defects incurred. Details from the technical log are entered onto an electronic database, which is regularly reviewed by various engineering departments for the purposes of safety management and maintenance planning.

The entry raised by the commander in G-EUOB's technical log following the incident would have been reviewed by engineers at London Heathrow, but given the limited information provided, it did not trigger any further investigation.

1.18 New investigation techniques

None were used in this investigation.

1.19 Additional information

1.19.1 Crew observations

The commander reported that at the time of the initial failure he was shocked by the loss of so much equipment. He considered it a very serious event that was outside of his previous experience in terms of the specific failure, and he also reported that he experienced a high degree of alarm when it happened.

The co-pilot reported that her initial reaction was that both engines had failed but that she soon realised that the aircraft was still climbing. She considered the information concerning the climb may have come from looking at her instruments immediately after the event and seeing for a short time a vertical speed indication on the PFD, however she was not certain.

1.19.2 Similar display blanking incidents

A review of the UK MOR database and discussions with Airbus revealed that there have been other similar events involving the reported blanking of the captain's and co-pilot's PFD and ND and the upper ECAM display. Details of these are provided as follows, according to date of occurrence, aircraft type and Manufacturer's Serial Number (MSN):

1. September 2005 Airbus A319 MSN 1088

   On descent out of 26,000 had a complete electrical failure. ***All screens blank****, #1 COMM inop, emergency lights came on in back (****still had bottom ECAM****). RAT did not deploy. Couldn't start APU. Selected 'ALTN' on AC ESS FEED. Got screens back. Able to reset GEN 1 and start APU.*

2. September 2000 Airbus A320 MSN 387

   Five display screens blanked *on short final to land. Fault found on IDG 1 current transformer.*

3. December 1998 Aibus A319 MSN 672

   Five displays blanked *just prior to lining up on the runway for take off. Chafing found on IDG 1 wiring.*

4. 12 December 1996 Airbus A320 MSN 348

Following No 1 engine shut down on stand, electrical power failed. TR 1 & AC ESS FEED faults illuminated on ECAM. ***Cabin lights & flight deck screens (except compacted lower ECAM) failed****. AC ESS FEED recycled without success. No 2 Generator Line Contactor (GLC) recycled, electrics returned. Inspection found No 1 AC bus unavailable due Bus Tie Connector (BTC) failed. Suspect electrics returned when No 2 GLC recycled due relay 4XU2 fault as this relay feeds No 2 GLC & No 1 BTC. Reporter comments on the potential hazard as it would not have been possible to recycle GLC had power failed during flight. Relay 4XU2 (P/N E0246-28AO) subsequently changed. Operation normal, unable to reproduce defect. Suspect high resistance contacts in BTC line contact above relay.*

5. 19 October 1996 Airbus A320 MSN 348

Electrical power failed to auto transfer from engine to APU electrical power with TR 1 fault ECAM message. APU GCU fault. ***Emergency lights illuminated & all screens except lower ECAM went blank****. RH engine shut down & AC Essential Feed selected - power restored, then AC Essential Feed switched off. Status maintenance showed DC bus tie fault which reporter suspects may have caused power loss. No 3 APU GCU (P/N 740120C) changed - subsequent operation satisfactory.*

The above incidents were investigated by Airbus, however the loss of the co-pilot's PFD and ND could not be reproduced and the cause of the co-pilot's display blanking could not be identified.

To date, the EIS display blanking events similar to the G-EUOB incident have only occurred on aircraft equipped with the EIS1 display configuration.

1.19.3 Certification standards

The certification standard relating to instruments systems applicable to the A320 family of aircraft is Joint Airworthiness Requirement (JAR) 25.1333 (now superseded by EASA CS 25.1333).

JAR 25.1333 (b) states:

> *For systems that operate the instruments required by JAR 25.1303 (b) which are located at each pilot's station:*
>
> *(b) The equipment, systems, and installations must be designed so that sufficient information is available to assure control of the aeroplane in speed, altitude, heading and attitude without immediate crew action after any single failure or combination of failures that is not assessed to be extremely improbable.'*

JAR 25.1309 supplementary material defines 'extremely improbable' as being a probability of less than one per 10^{-9} flying hours (once per thousand million flight hours). The A320 fleet had flown, up to August 2006, in excess of 50 million flight hours. This is the sixth reported occurrence of a failure involving the loss of the same five electronic flight displays on A320 family aircraft.

2 Analysis

2.1 Operational aspects

2.1.1 Crew qualifications, experience and training

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

Neither crew member had any previous experience of flying Airbus A320 family aircraft using the standby instruments alone. On this occasion the conditions were such that the pilot was able to see and make reference to the external horizon; however this may not always be the case. There is no provision during Airbus initial or recurrent training programmes for practice in flight with sole reference to the standby instruments. It is likely that many pilots flying A320 family aircraft may never have practised flight by sole reference to the standby instruments provided on the aircraft. This incident and other similar events, suggests that pilots may need to fly with reference to these instruments more often than has been previously envisaged. The need for the flight crew to be proficient for such flight is not limited to any particular aircraft type, and recurrent training should be provided by the operators. The following Safety Recommendation is therefore made:

> It is recommended that the European Aviation Safety Authority should, in consultation with other National Airworthiness Authorities outside Europe, consider requiring training for flight by sole reference to standby instruments for pilots during initial and recurrent training courses. (Safety Recommendation 2007-062)

2.1.2 Response to the electrical failure

This event had never previously been experienced by either crew member. When the power failed, the autopilot disconnected and the EFIS and other essential systems were no longer available so the commander, who was PF, took manual control and used the visual and standby horizons to maintain controlled flight. He continued to comply with the last ATC clearance by climbing and levelling off at what he remembered, correctly, to be the cleared flight level. The LAM TC sector is usually very busy and a deviation from a clearance could have posed a risk of a loss of separation.

The co-pilot's initial reaction to the darkened flight deck was that both engines might have failed, but she soon recognised that the aircraft was still climbing and that it must therefore be an electrical failure. The general principle of managing the ECAM is to confirm a failure by reviewing the affected system synoptic page and then to carry out the ECAM actions. In this case the electric system page was not readily available and therefore an overview of the failure was not obtained.

The ECAM actions were carried out in sequence but took some time to perform because of the difficulty in finding particular switches on the now dark overhead panel. The co-pilot took care to ensure that the right action was carried out and that she had correctly identified each switch before using it. As a result some ninety seconds elapsed before the 'AC ESS FEED' switch was selected, and power was restored to most of the essential systems.

During this time the commander's attention was primarily focused on flying the aircraft and he was not able to follow all of the ECAM actions as they were performed. However once power was restored and the aircraft was back in a more usual flight configuration he handed over control to the co-pilot. This action allowed him time to review the status of the aircraft and to communicate with Maintrol.

2.1.3 Decision to continue the flight

The aircraft was directed to a holding pattern to allow the commander more time to assess the event and to consider whether the flight should continue to Budapest or return to London. There were a number of other actions being carried out by him during this time; these included liaising with Maintrol, communications with the cabin crew and the passengers, searching for and checking circuit breakers, and consulting onboard documentation. There was sufficient fuel on board for several hours of holding time if required. If an immediate return to land had been carried out the aircraft would have been over the normal maximum landing mass; however there was a straightforward procedure for this eventuality.

The commander had reviewed the ECAM following the recovery of the majority of the electrical services and had noted the remaining unserviceabilities. Observing that the TR 1 was the only item on the ECAM electrical systems page which remained amber, he incorrectly concluded that a failure of the TR 1 was the root cause of all the failures. In fact the loss of TR 1 is the normal result of a loss of power to AC BUS 1; the resetting of a TR is not covered by an operational procedure for the flight crew and so an offline TR will normally remain unavailable until reset on the ground by the maintenance crew.

In the commander's communications with Maintrol he passed on information that there was a TR 1 fault; he also transmitted the more significant information about the preceding substantial loss of instruments, lighting and systems. This was not fully understood by the Maintrol personnel because of poor reception and interruptions during the communications. The commander also reported to them that the ACC ESS FEED push button had been used to restore the power, but this transmission again was not heard and when asked to repeat the fault the commander only passed the information that TR 1 had failed. Maintrol personnel therefore had an incomplete understanding of the failure.

Having considered the information received from the commander and having checked the MEL and maintenance documentation, Maintrol advised him that it should be possible for local maintenance personnel in Budapest to dispatch the aircraft for its return sector.

The commander still had to decide whether to continue the flight to Budapest. In view of the unusual nature of the event and the alarm clearly experienced by the pilots when it happened, it is worth examining the reasons behind his eventual decision to continue the flight. To make this decision he needed to take into consideration the implications of the effect of the unavailable systems on the aircraft, such as the windshield and window heating and the weather forecasts en-route and at destination, as well as the advice from Maintrol.

The weather conditions at Heathrow were considerably better than those forecast for Budapest. Immediately after the loss of electrical power the commander had attempted to declare a MAYDAY, an action which indicates that at that time he had a serious concern about the safety of the aircraft. However, because he was subsequently working on the false premise that a TR 1 fault was the source of the failure, he apparently did not take into consideration that the original failure could recur. Clearly, a similar loss of instrumentation at a critical phase of flight could have had more serious consequences. Had he been aware of any significant remaining unserviceability, or had there been less certainty in his own mind about the nature of the failure, he probably would have returned to Heathrow. In the event, the meteorological conditions at Budapest caused the commander's windscreen to either mist or ice over and resulted in both the landing and taxiing being carried out by the co-pilot. Although these were normal operating procedures for a co-pilot, it was not desirable for the commander to be unable to visually monitor the landing and taxiing, particularly with the degraded status of the aircraft and the relatively poor weather.

2.1.4 ECAM procedures

In most failure circumstances the affected system page would be automatically called up. The procedure is to review the page to confirm the failure and then to carry out the ECAM actions. The presentation of the ECAM checklist is such that when an item is actioned it is then cleared from view. It can be recalled later if so desired but this does not form part of the procedure. The result is that once an action is complete the crew can lose sight of what failures have taken place, particularly so in this case where the system page was not readily available and the commander was almost completely engaged upon the flying task until the instruments were restored.

The systems that remained inoperative after completion of the ECAM actions were not necessarily an indication of the nature of the original failure. This fact appears to have misled the crew, and in turn led to incorrect information being passed to Maintrol and the station engineer at Budapest.

2.1.5 Post-flight actions

The commander's technical log entry did not include any information about the initial failure event but reflected the status of the aircraft after the ECAM actions were completed. There was no entry to the effect that the 'AC ESS FEED' push button had been used. Only the ASR documented the actual symptoms of the electrical failure. It is likely that the commander assumed he had passed on sufficient information verbally, both to Maintrol and to the engineer at Budapest, to allow the failure to be properly understood.

The station engineer took action to reset the inoperative systems but it appears that he did not consider the ASR to have formed part of the reported aircraft defects. The engineering actions he took prior to despatch were limited to a reset of the TR 1 and the EPR mode; there was no further troubleshooting by him as to the reason for the failure. Therefore the aircraft was despatched for the next flight following a significant failure of the electrical system, without any comprehensive fault finding having been carried out.

One additional consequence of not putting more information in the technical log was that the next operating crew remained unaware that there had been a significant loss of electrical equipment on the previous sector. Thus, if the failure had recurred on the next sector the crew would not have had any information about the nature of the earlier failure.

2.2 EIS display blanking

The simultaneous loss of both the captain's and co-pilot's PFD and ND theoretically should not be possible, given that they are powered from independent electrical networks. However, this and other similar incidents show that there is an unforeseen common failure mode which can cause the simultaneous loss of both the pilot and co-pilot's EFIS instruments and the upper ECAM display.

The co-pilot recalled having possibly seen a vertical speed indication on the PFD for a few moments but could not be certain. Notwithstanding this, even if some information was visible on the co-pilot's PFD, the display was degraded to the point where it was unusable.

Airbus testing of the electrical system on the 'iron bird' did not reproduce the failure of the co-pilot's EFIS screens and reviews of the electrical system and EIS architecture did not identify any obvious failure scenarios that could cause the simultaneous loss of the captain's and co-pilot's EFIS displays. This therefore remains a cause for concern.

2.3 ECAM issues

Whilst the cause of the incident remains undetermined, the crew were able to recover most of the affected systems after about 90 seconds by selecting the AC ESS FEED push button to 'ALTN' while carrying out the ECAM actions. The delay in performing this action was largely due to the fact that it was not one of the first items on the list of ECAM actions and was therefore not initially visible on the lower ECAM display. This inevitably caused a delay due to the fact that the co-pilot was required to clear each item sequentially in the order that they appeared. The delay was also partly due to the degraded lighting in the cockpit.

The loss of both the pilot's and co-pilot's PFDs and NDs, at a critical phase of flight in Instrument Meteorological Conditions (IMC), could affect the safe operation of the aircraft. Given that on some aircraft, there is the potential that the standby horizon could also be unpowered during such an incident, such a delay in recovering the EFIS displays is undesirable. The following Safety Recommendation was therefore made during the investigation and was published April 2006 in AAIB Special Bulletin 3/2006:

> It is recommended that the aircraft manufacturer, Airbus, reviews the existing ECAM actions for the A320-series aircraft, given the possibility of the simultaneous in-flight loss of the commander's and co-pilot's primary flight and navigation displays. They should consider whether the priority of the items displayed on the ECAM should be altered, to enable the displays to be recovered as quickly as possible and subsequently issue operators with a revised procedure if necessary. (Safety Recommendation 2006-051)

2.3.1 MMEL relief for lower ECAM

The A318/A319/A320/A321 MMEL allows the aircraft to be dispatched with five of the six EIS screens operative, provided that the upper ECAM display is operative. It is therefore permissible for the aircraft to operate with the lower ECAM display inoperative, for a period of up to ten days.

The safety analysis performed at the time the MMEL item was approved could not be expected to have foreseen the circumstances of this incident. However, given that it is possible to lose the captain's and co-pilot's PFD and ND and the upper ECAM simultaneously, as this and other incidents have demonstrated, this MMEL item should now be reviewed. In this case, the lower ECAM was the only display left available to the crew and it showed the list of actions which enabled the crew to recover most of the affected systems. Had it not been available, the crew would have had no readily accessible information on the appropriate actions to be taken.

The following Safety Recommendation was therefore made during the investigation and was published April 2006 in AAIB Special Bulletin 3/2006:

> It is recommended that the aircraft manufacturer, Airbus, should review the A320-series aircraft Master Minimum Equipment List Chapter 31, INDICATING/RECORDING SYSTEMS and reconsider whether it is acceptable to allow the ECAM lower display unit to be unserviceable. They should amend the requirement, as necessary, to take account of the possibility of the simultaneous in-flight loss of both the commander's and co-pilot's primary flight and navigation displays and the ECAM upper display. (Safety Recommendation 2006-052)

2.4 Standby instruments

On some of the A320 family aircraft the standby instruments are not independently lit and powered, so that they cannot be taken into consideration when assessing the reliability of the system as a whole for the purposes of JAR 25.1333(b).

2.4.1 Standby horizon power supply

The unexplained simultaneous malfunctions of the commander's and co-pilot's primary flight instruments has significant implications for those aircraft with the pre-ISIS wiring configuration for the standby instruments. If this incident had occurred to one of these aircraft, the standby horizon would no longer have been powered and would have become unusable after approximately five minutes, leaving the crew without any instrumented attitude reference. This would preclude their ability to maintain control of the aircraft in conditions where there is no visible external horizon.

The following Safety Recommendation was therefore made during the investigation and was published April 2006 in AAIB Special Bulletin 3/2006:

> The aircraft manufacturer, Airbus, should identify those aircraft with the single power supply to the standby artificial horizon and advise the operators of the potential implications of this configuration. (Safety Recommendation 2006-053)

Also, the following Safety Recommendations is now made:

> Airbus should introduce a modification for A320 family of aircraft which have the pre-ISIS wiring configuration for the standby instruments, in order to provide a back-up power supply which is independent of the aircraft's normal electrical power generation systems. (Safety Recommendation 2007-063)

Since the issue of Special Bulletin 3/2006, Airbus has advised that Modification 37317 has been introduced by Service Bulletin SB A320-24-1120 issued May 2007. This modification provides an automatic reconfiguration of the power supply to the AC ESS bus in the event of AC 1 bus failure. This modification largely satisfies the intent of Safety Recommendation 2007-063. However, only the Regulatory Authority can mandate it. Therefore the following Safety Recommendation is also made:

> The European Aviation Safety Agency should mandate either Airbus Service Bulletin SB A320-24-1120 or the provision of a back-up power supply for the standby horizon which is independent of the aircraft's normal electrical power generation systems, on A320 family aircraft. (Safety Recommendation 2007-064)

It was found that the information contained in the A320-series Flight Crew Operating Manuals did not reflect the differences in the power supply configurations for the standby horizon for pre- and post-ISIS wiring configuration aircraft. The following Safety Recommendation was therefore made during the investigation and was published April 2006 in AAIB Special Bulletin 3/2006:

> It is recommended that the aircraft manufacturer, Airbus, revises the information about the power sources for the standby artificial horizon provided in Flight Crew Operating Manuals for the A320-series aircraft to reflect the actual status of the aircraft to which they apply. (Safety Recommendation 2006-054)

In response to this Safety Recommendation, Airbus has reviewed the relevant Flight Crew Operating Manual pages and updated them accordingly.

2.5 Cockpit and standby instrument lighting

On all A320 family aircraft, irrespective of whether the standby horizon remains powered, the loss of the left electrical network results in the loss of the integral lighting for the standby instruments. Trials in night conditions showed that the standby instruments may be unusable due to lack of sufficient lighting, particularly if the dome lights are switched off. In this and other similar incidents involving the simultaneous loss of the captain's and co-pilot's EFIS instruments, the standby horizon is the only available attitude reference instrument in the absence of a visible horizon. Therefore the standby instruments must be lit in order to meet the requirements of JAR 25.1333 (b).

The following Safety Recommendations are therefore made:

> In order to ensure that the standby instruments on A320 family aircraft remain adequately illuminated following the loss of the left electrical network, Airbus should introduce a modification to provide a power supply for the standby instrument integral lighting which is independent of the aircraft's normal electrical power generating systems. (Safety Recommendation 2007-065)

> The European Aviation Safety Agency should mandate the provision of a power supply for the standby instrument integral lighting which is independent of the aircraft's normal electrical power generating systems, on A320 family aircraft. (Safety Recommendation 2007-066)

In response to Safety Recommendation 2007-065 while it was still at the draft stage, Airbus advised that Service Bulletin A320-33-1057 had been issued in May 2007 to introduce Modifications 37329 and 37330. These modifications provide a backup supply to the cockpit floodlight above the standby instruments.

2.6 Other systems affected

The loss of the left electrical network has a significant impact on the availability of important aircraft systems and any significant delay in recovering these systems is undesirable. Airbus have advised that they have observed that the average time for crew selection of the AC ESS FEED to 'ALTN' following a failure is around one minute. The loss of the EIS displays and cockpit lighting have already been discussed, however other systems are affected which may impact on safety, particularly in a busy airspace environment. The loss of the flight interphone made it more difficult for the flight crew to communicate with one another in an already difficult situation. The loss of VHF1 and VHF2 radios will delay the crew in advising ATC of the aircraft's situation and their intentions. The loss of ATC1, if selected, means that the transponder will be inoperative and the aircraft's details, including its altitude will not be visible on ATC radar screens. Furthermore, the TCAS and EGPWS systems are degraded, reducing the level of protection against collision with other aircraft and terrain. The following Safety Recommendation is therefore made:

> Airbus should conduct a study into the feasibility of automating the reconfiguration of the power supply to the AC Essential bus, in order to reduce the time taken to recover important aircraft systems on A320 family aircraft following the loss of the left electrical network. (Safety Recommendation 2007-067)

In response to this Safety Recommendation, while it was at the draft stage, Airbus issued Service Bulletin SB A320-24-1120 in May 2007. This introduced Modification 37317 which provides automatic reconfiguration of the power supply to the AC ESS Bus in the event of AC1 Bus failure.

A review of the other systems reported to have been affected during the incident showed that these received power from the left electrical network. Their degradation or failure was therefore consistent with the loss of the left electrical network.

2.7 DAR data analysis

2.7.1 The electrical power and display failures

The DAR data and the crew reports of the symptoms experienced during the incident are generally consistent with the loss of busses powered by the No 1 generator, which includes AC BUS 1, the AC ESS bus, DC ESS bus and DC BUS 1. The loss of the left network would be expected to produce the reported symptoms including, but not limited to: the loss of the captain's PFD, ND; the upper ECAM display; most of the cockpit lighting; VHF1 and VHF2 radios and the ATC1 transponder. However, the degradation or loss of the co-pilot's EFIS displays is not expected, given that they are powered from AC BUS 2. No evidence was found which could account for this.

2.7.2 DC Electrical power parameters

The only reliable parameters relating to the DC network are whether DC BUS 1 and DC BUS 2 were powered. With the exception of the loss of DC BUS 1 for between 4 and 12 seconds right after the loss of the No 1 generator, both DC networks remained powered. Analysis of systems powered from the DC ESS and DC ESS SHED buses shows that these failed at the start of the incident, and were recovered 90 seconds later when the crew selected the AC ESS FEED to 'ALTN'.

2.7.3 AC Electrical power parameters

The No 1 generator load fell to zero with the aircraft in the climb to FL230. This removed power from AC BUS 1, therefore powering down the AC ESS and AC ESS SHED buses. The lack of power to the blue hydraulic system shows that the power to AC BUS 1 was not restored by automatic bus transfer of AC BUS 1 power to the No 2 generator.

Ninety seconds after the loss of the No 1 generator, the power to the AC ESS bus and AC ESS SHED buses was restored. The blue hydraulic system remained unpowered so the restoration of power was not via AC BUS 1 so must have been via the AC ESS bus transfer contactor in reaction to crew selection of the AC ESS FEED to 'ALTN'.

Forty-five seconds later, the No 1 generator took up load and the blue hydraulic system pressure increased to nominal values, indicating that the No 1 generator was now powering AC BUS 1 as per normal.

2.7.4 DMC2/3 transfer discrete

Testing at Airbus demonstrated that an electrical anomaly associated with the DMC2/3 transfer discrete could result in the transfer of the ND and PFD to DMC3 whilst leaving the lower ECAM linked to DMC2. This would match the recorded data and the crew observations. As yet there is no explanation of how this condition could have been switched on by the power failure and subsequently switched off by the power recovery.

There have been multiple other reported occurrences in which an unknown link between the electrical power loss on the captain's side and display loss on the co-pilot's side has degraded safety margins. Given the nature of operator reporting, it is likely that the occurrence rate is actually higher than the known cases would indicate. Being unknown, this link would not have been considered when carrying out the safety analysis of the instrument systems at the time the systems were certified.

2.7.5 Hydraulics

The hydraulic parameters indicate that the yellow and green systems were unaffected by the events of the flight. The blue system failed for the whole duration that the No 1 generator was off line. The brief glitches in the blue low hydraulic pressure indication discretes are just after rudder movements. It is possible that the rudder movement, controlled via the other hydraulic systems, produced sufficient back pressure, via the blue system actuator, to get above the low pressure sensing threshold.

During the two minutes and 15 second period without blue hydraulics, the only affected systems with no alternative hydraulic source would have been No 3 spoilers, left and right.

2.8 Generator control unit issues

According to the DAR data, the No 1 generator load fell to zero at the start of the incident, indicating that the No 1 generator was no longer powering the left electrical network. The electrical system did not automatically reconfigure itself to power the left network from the No 2 generator by the closure of the

Bus Tie Contactors. There are two possible explanations for this. The first is that GCU 1 may have detected a fault in Zone 2, triggering a genuine DP2 fault detection, which would have inhibited the automatic reconfiguration by locking out the BTCs. However, evidence against this is the lack of any record of a DP2 event in the GCU fault memory. The second possibility, based on Airbus' experience, is that GCU 1 experienced a false DP2 detection, due to an intermittent fault in Zone 1, such as a short in the IDG, the IDG feeders or a fault in a current transformer. Whatever the fault may have been, there was no record of it in the GCU 1 NVM and there has been no recurrence and there is no history of previous similar incidents on G-EUOB.

The lack of fault records in the GCU NVM and the potential for false DP2 detections which can result in the loss of the affected electrical network is undesirable. The following Safety Recommendation is therefore made:

> Airbus, in conjunction with the Generator Control Unit (GCU) manufacturer Hamilton Sundstrand, should modify the A320 family GCUs to provide the capability to record intermittent faults and to reduce their susceptibility to false differential protection trips. (Safety Recommendation 2007-069)

2.9 Certification standards

The intent of the JAR 25.1333 (b) certification standard requires that the flight instruments specified in JAR 25.1303 (b) remain available, so that the crew can control the aircraft in speed, altitude, heading and attitude after any single failure or combination of failures that is not assessed to be 'extremely improbable'. This is the sixth reported incident involving the loss of the same five EIS displays, which shows that the failure is not an isolated occurrence. At least one unforeseen failure mode exists which results in the simultaneous loss of the captain's and co-pilot's EFIS instruments, the upper ECAM display and the instrument integral lighting. Most importantly, on some aircraft the standby horizon is also unpowered although it remains useable for 5 minutes after the loss of the ESS busses.

The certification standards specify the requirements for a new aircraft design; however in-service experience with an aircraft type may highlight failure modes which could not be anticipated during the design phase. The impact of such failures on airworthiness must be considered and appropriate actions taken to reduce the level of risk to flight safety.

2.10 Recorder technology

The FDR and CVR recordings were insufficient to determine what information, if any, was presented to the crew on their electronic displays during this event. An additional image recording of these displays only would have provided a more rapid and detailed understanding of the circumstances with the result that corrective action could have been instigated at an early stage of the investigation.

Image recording

The UK Civil Aviation Authority conducted a trial to establish the effectiveness of airborne image recorders. One of the conclusions of the report (CAP 762) was that "this research has shown that image recorder systems can provide clear evidence of the failure of electronic displays." It further concluded that "it has also been shown that image recorder systems provide images of sufficient resolution to enable investigators to identify both missing data and data fail flags." The FAA has commissioned a similar study.

A technical standard for such airborne image recorders has already been developed by the European Organisation for Civil Aviation Equipment (EUROCAE) and was issued as a Minimum Operational Performance Specification (ED-112) in March 2003. Although the technology to provide such an image recording is defined and is in existence, only a few countries have developed the legislation to provide the same legal protection as is afforded to cockpit voice recordings. A review of the applicable UK secondary legislation has been initiated with a view to providing such protection. ICAO is also considering this issue and whether to recommend the use of such image recorders for those aircraft where it is impractical, through cost or design, to record some information on a flight data recorder.

This investigation would have been greatly assisted by flight deck image recording, and the AAIB is aware of a number of similar cases where, for technical reasons or because of imperfect recollection of events by the crew, image recording would have been very useful. Therefore the following Safety Recommendation is made:

> The International Civil Aviation Organisation should expedite the introduction of a standard for flight deck image recording, and should encourage member states to provide legal protection, similar to that for cockpit voice recordings, for such image recordings. (Safety Recommendation 2007-070)

BITE recording

The system manufacturers deemed it necessary to amend the BITE of the systems involved in this investigation to overcome the shortcomings of the current BITE so that future occurrences can be better understood. Accordingly, DMC BITE improvements were introduced in a recent certified standard (DMC V60). The FDR does not record BITE data. If there were an accident whereby only crash protected recordings were recoverable, there would be less evidence available than there was for this investigation. Avionic systems are increasingly important to safe flight, yet their increasing complexity makes it difficult to investigate what they were doing at the time they failed to work as per design, without the benefit of very system specific data.

Currently FDR recordings are based on regular sampling of parameters. BITE recording is event-driven, not sample-driven, meaning that most of the time there is nothing to record but under abnormal conditions there are sporadic bursts of data to record.

2.11 Organisational procedures

A substantial period of time passed before the significance of this incident was recognized by the airline. There were two main reasons for this:

Firstly, the commander did not describe the full symptoms of the incident in the aircraft technical log, rather only those defects that were still outstanding on arrival at Budapest. This meant that the Air Safety Report completed by the commander was the only written record containing the full details of the incident. Although the commander had described the incident to the station engineer, the engineer had not fully understood the implications of the incident, based on his actions of simply addressing the faults recorded in the technical log, prior to declaring the aircraft serviceable.

If the aircraft technical log had contained comprehensive details of the incident, this information would have been seen by company engineers responsible for monitoring the aircraft's serviceability, who would probably then have carried out further investigation. The fact that it did not contain this information meant that this vital opportunity was missed.

Secondly, given that the ASR was the only written record containing the full description of the event, it was imperative that the faxed copies were sent to the Flight Operations Safety Department and the World Network Services department in Mumbai, for entering onto the Airline's electronic safety management database. For reasons which could not be determined, the faxed copies were not received, with the result that the FOSD did not become fully aware of the incident until four days later, when the original copy of the ASR arrived in the post. This resulted in a considerable delay before any subsequent safety actions were taken.

The following Safety Recommendation is therefore made:

> British Airways PLC should review the advice given to flight crew concerning aircraft Technical Log entries, where an Air Safety Report (ASR) is also raised, to ensure that the aircraft Technical Log fully records the details of serious incidents and to ensure, as far as possible, that ASRs are received by the Flight Operations Safety Department in a timely a manner, irrespective of where the ASR is raised. (Safety Recommendation 2007-071)

3 Conclusions

3.1 Findings

3.1.1 Personnel

1. The flight crew were licensed and qualified to operate the flight.

2. The flight crew were in compliance with the applicable flight time and duty time limitations.

3. The flight crew had not received any formal training on how to operate A320-family aircraft by sole reference to the standby instruments.

4. The commander did not record the full details of the incident in the aircraft technical log, however he did record this information on the Air Safety Report which he filed.

5. The engineer in Budapest (who was not an employee of the airline), did not investigate the symptoms of the incident which were reported to him verbally by the commander and which were also recorded in the Air Safety Report.

3.1.2 The aircraft

1. The aircraft held a valid Certificate of Airworthiness and no relevant recorded defects were being carried.

2. The aircraft was maintained in accordance with an EASA-approved maintenance programme.

3. The aircraft suffered the loss of the left electrical network, for reasons which could not be established. A possible explanation is the detection of a false DP2 condition by the No 1 Generator Control Unit, but this could not be confirmed.

4. The loss of the left electrical network caused various systems powered by the left network to either cease operating, or become degraded. These systems included, most notably, the autopilot, the autothrust system, the captain's and co-pilot's Primary Flight and Navigation Displays, the upper ECAM display, most of the cockpit lighting, including the integral lighting to the instruments and standby instruments, the VHF 1 and VHF 2 radios and the ATC 1 transponder.

5. The majority of the aircraft systems were recovered after approximately 90 seconds, after selection of the AC ESS FEED switch, in accordance with the ECAM procedure. AC BUS 1 was recovered after approximately 135 seconds, by cycling of the No 1 generator switch.

6. This and other similar incidents show that there is at least one unforeseen failure mode on A320 family aircraft, which can cause the simultaneous loss of the captain and co-pilots electronic flight instruments and the upper ECAM display.

7. Aircraft equipped with an electromechanical standby horizon and not provisioned with the ISIS wiring configuration have a single power supply to the standby horizon, from the DC ESS bus. If this incident had occurred to such an aircraft, the standby horizon would have been unpowered and become unusable after approximately five minutes.

8. The A318/A319/A320/A321 MMEL allows the aircraft to be dispatched with the lower ECAM display inoperative. In this case, it was the only display available and presented the list of actions, which enabled the crew to recover most of the failed systems.

9. Trials showed that in night conditions, there may be insufficient light available to see the standby instruments following the loss of the left electrical network, particularly if the cockpit dome light is off.

3.1.3 Organisational

1. The information contained in the ASR raised by the commander should also have been reflected in the aircraft technical log. The technical log did not contain important details of the incident; as a result it reflected only minor defects which were rectified without appreciation of the importance of the serious incident which had occurred.

2. The faxed copies of the Air Safety Report raised by the commander were not received by the airline's Flight Operations Safety Department, or the department responsible for entering the incident data on to the electronic safety management database. As a result of this and of the minimal information contained in the Technical Log, the significance of the incident was not fully understood until the original copy of the ASR arrived in the post at London Heathrow.

3.1.4 Recorded flight data

1. Airbus has found a failure mode by which the co-pilot's ND and PFD could have been switched from the functional DMC2 to the failed DMC3 whilst leaving the lower ECAM linked to DMC2, however, no link has been found between this failure mode and the failure of power on the aircraft.

2. Because the mechanism by which the power failure on the captain's side resulted in the additional loss of the co-pilot's instruments is not known, it cannot have been considered when analysing failure modes for compliance with requirements.

3. The system BITE designs have been improved to better capture this type of failure. BITE is not recorded by the FDR. Detailed evidence may be lost in the event of an accident caused by the failures involved in this incident.

4. The display behaviour was not apparent from the recorded data. Only the crew observations revealed the extent of the problem. This evidence may be lost in the event of an accident.

5. A crash protected image recording of the instruments would have provided more detail to this investigation and provided crucial evidence that may otherwise have been missing had crew observations not been available.

3.2 Causal factors

The investigation identified the following causal factors:

1. The aircraft suffered the loss of the left electrical network, resulting in loss of the captain's PFD and ND, and the upper ECAM display, for reasons which could not be determined.

2. A co-incident failure caused the co-pilot's Primary Flight Display and Navigation Display to blank or become severely degraded, at the same time as the loss of the left electrical network. The origin of the co-incident failure could not be identified.

4 Safety Recommendations

The following Safety Recommendations were made during this investigation and were published in April 2006 in AAIB Special Bulletin 3/2006:

4.1 **Safety Recommendation 2006-051**: It is recommended that the aircraft manufacturer, Airbus, reviews the existing ECAM actions for the A320-series aircraft, given the possibility of the simultaneous in-flight loss of the commander's and co-pilot's primary flight and navigation displays. They should consider whether the priority of the items displayed on the ECAM should be altered, to enable the displays to be recovered as quickly as possible and subsequently issue operators with a revised procedure if necessary.

Airbus has responded to this Safety Recommendation stating that it would not be acceptable to change the priority of the ECAM action items for the following reasons:

- there are other failure modes in which the selection of the AC ESS FEED is not the most important action,
- the current ECAM action prioritisation was arrived at after taking into account many different safety analyses,
- Changing the priority of the ECAM items would require validation on all airframe engine combinations and could have an impact on other engine or electrical alerts,
- New priorities could introduce new operational issues which would need to be reviewed and approved by the regulatory authorities (EASA/FAA).

4.2 **Safety Recommendation 2006-052**: It is recommended that the aircraft manufacturer, Airbus, should review the A320-series aircraft Master Minimum Equipment List Chapter 31, INDICATING/RECORDING SYSTEMS and reconsider whether it is acceptable to allow the ECAM lower display unit to be unserviceable. They should amend the requirement, as necessary, to take account of the possibility of the simultaneous in-flight loss of both the commander's and co-pilot's primary flight and navigation displays and the ECAM upper display.

In response to this Safety Recommendation, Airbus has reviewed the content of the A318/A319/A320/A321 MMEL regarding dispatch with the lower ECAM display inoperative.

MMEL Sections 1 and 2 were updated in August 2006 to include the condition that an operational test of the AC Essential bus transfer function and indication must be performed once per day if the lower ECAM is inoperative. The Aircraft Maintenance Manual will also be updated to include the test procedure.

This Safety Recommendation was made to ensure that the operating crew would always have information presented on ECAM as to the actions required to recover the systems should a similar event occur. The response of Airbus to the recommendation did not address this problem, which is that if the Lower ECAM screen were not available, in the event of a similar failure, there would not be any information displayed to the crew as to what action they should take to recover the systems. Accordingly, Airbus propose to amend the A320 family MMEL section 2 regarding dispatch with the lower ECAM inoperative, to remind crews of the necessary recovery action should the AC ESS bus, and therefore all DUs be lost:

> 'In case of failure of AC Bus 1, all DUs are lost:
> - Apply AC ESS BUS FAULT procedure of FCOM 3.02.24 (Select AC ESS FEED at ALTN) to recover AC ESS BUS'

4.3 **Safety Recommendation 2006-053**: The aircraft manufacturer, Airbus, should identify those aircraft with the single power supply to the standby artificial horizon and advise the operators of the potential implications of this configuration.

In response to this Safety Recommendation Airbus has advised operators through OIT 9SE999.0115/05/BB Rev 1, that for aircraft without the ISIS wiring configuration to the standby instruments, the standby horizon may be unusable after five minutes if the DC ESS bus is lost.

4.4 **Safety Recommendation 2006-054**: It is recommended that the aircraft manufacturer, Airbus, revises the information about the power sources for the standby artificial horizon provided in Flight Crew Operating Manuals for the A320-series aircraft to reflect the actual status of the aircraft to which they apply.

In response to this Safety Recommendation Airbus has updated A320 family Flight Crew Operating Manual Section 3.02.24 page 11, Section 1.34.20 page 1 and Section 1.34.97 page 1 to reflect the different power supply configurations for the standby horizon.

The following additional Safety Recommendations are also made:

4.5 **Safety Recommendation 2007-062**: It is recommended that the European Aviation Safety Authority should, in consultation with other National Airworthiness Authorities outside Europe, consider requiring training for flight by sole reference to standby instruments for pilots during initial and recurrent training courses.

4.6 **Safety Recommendation 2007-063:** Airbus should introduce a modification for A320 family of aircraft which have the pre-ISIS wiring configuration for the standby instruments, in order to provide a back-up power supply which is independent of the aircraft's normal electrical power generation systems.

Since the issue of Special Bulletin 3/2006, Airbus has advised that Modification 37317 has been introduced by Service Bulletin SB A320-24-1120 issued May 2007. This modification provides an automatic reconfiguration of the power supply to the AC ESS bus in the event of AC 1 bus failure. This modification largely satisfies the intent of Safety Recommendation 2007-063.

4.7 **Safety Recommendation 2007-064:** The European Aviation Safety Agency should mandate either Airbus Service Bulletin SB A320-24-1120 or the provision of a back-up power supply for the standby horizon which is independent of the aircraft's normal electrical power generation systems, on A320 family aircraft.

4.8 **Safety Recommendation 2007-065:** In order to ensure that the standby instruments on A320 family aircraft remain adequately illuminated following the loss of the left electrical network, Airbus should introduce a modification to provide a power supply for the standby instrument integral lighting which is independent of the aircraft's normal electrical power generating systems.

In response to Safety Recommendation 2007-065 while it was still at the draft stage, Airbus advised that Service Bulletin A320-33-1057 had been issued in May 2007 to introduce Modifications 37329 and 37330. These modifications provide a backup supply to the cockpit floodlight above the standby instruments.

4.9 **Safety Recommendation 2007-066:** The European Aviation Safety Agency should mandate the provision of a power supply for the standby instrument integral lighting which is independent of the aircraft's normal electrical power generating systems, on A320 family aircraft.

4.10 **Safety Recommendation 2007-067**: Airbus should conduct a study into the feasibility of automating the reconfiguration of the power supply to the AC Essential bus, in order to reduce the time taken to recover important aircraft systems on A320 family aircraft following the loss of the left electrical network.

In response to this Safety Recommendation, while it was at the draft stage, Airbus issued Service Bulletin SB A320-24-1120 in May 2007. This introduced Modification 37317 which provides automatic reconfiguration of the power supply to the AC ESS Bus in the event of AC BUS 1 failure.

4.11 **Safety Recommendation 2007-069:** Airbus, in conjunction with the Generator Control Unit (GCU) manufacturer Hamilton Sundstrand, should modify the A320 family GCUs to provide the capability to record intermittent faults and to reduce their susceptibility to false differential protection trips.

4.12 **Safety Recommendation 2007-070:** The International Civil Aviation Organisation should expedite the introduction of a standard for flight deck image recording, and should encourage member states to provide legal protection, similar to that for cockpit voice recordings, for such image recordings.

4.13 **Safety Recommendation 2007-071:** British Airways PLC should review the advice given to flight crew concerning aircraft Technical Log entries, where an Air Safety Report (ASR) is also raised, to ensure that the aircraft Technical Log fully records the details of serious incidents and to ensure, as far as possible, that ASRs are received by the Flight Operations Safety Department in a timely a manner, irrespective of where the ASR is raised.

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