AIRCRAFT ACCIDENT REPORT 2/2008

Air Accidents Investigation Branch

Department for Transport

Report on the serious incident to Airbus A319-131, G-EUOB during the climb after departure from London Heathrow Airport on 22 October 2005

This investigation was carried out in accordance with
The Civil Aviation (Investigation of Air Accidents and Incidents) Regulations 1996

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.

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.

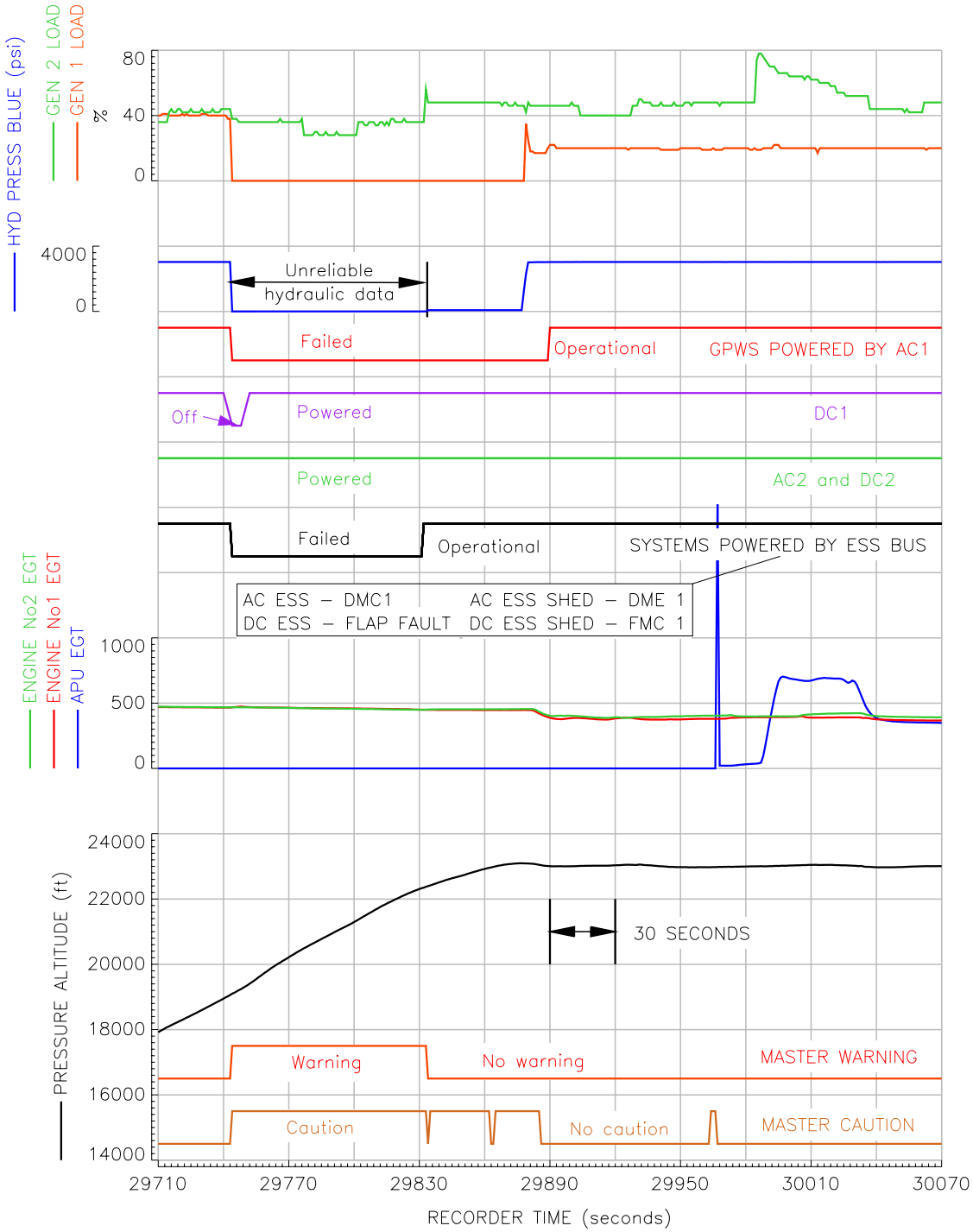

Figure 9

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

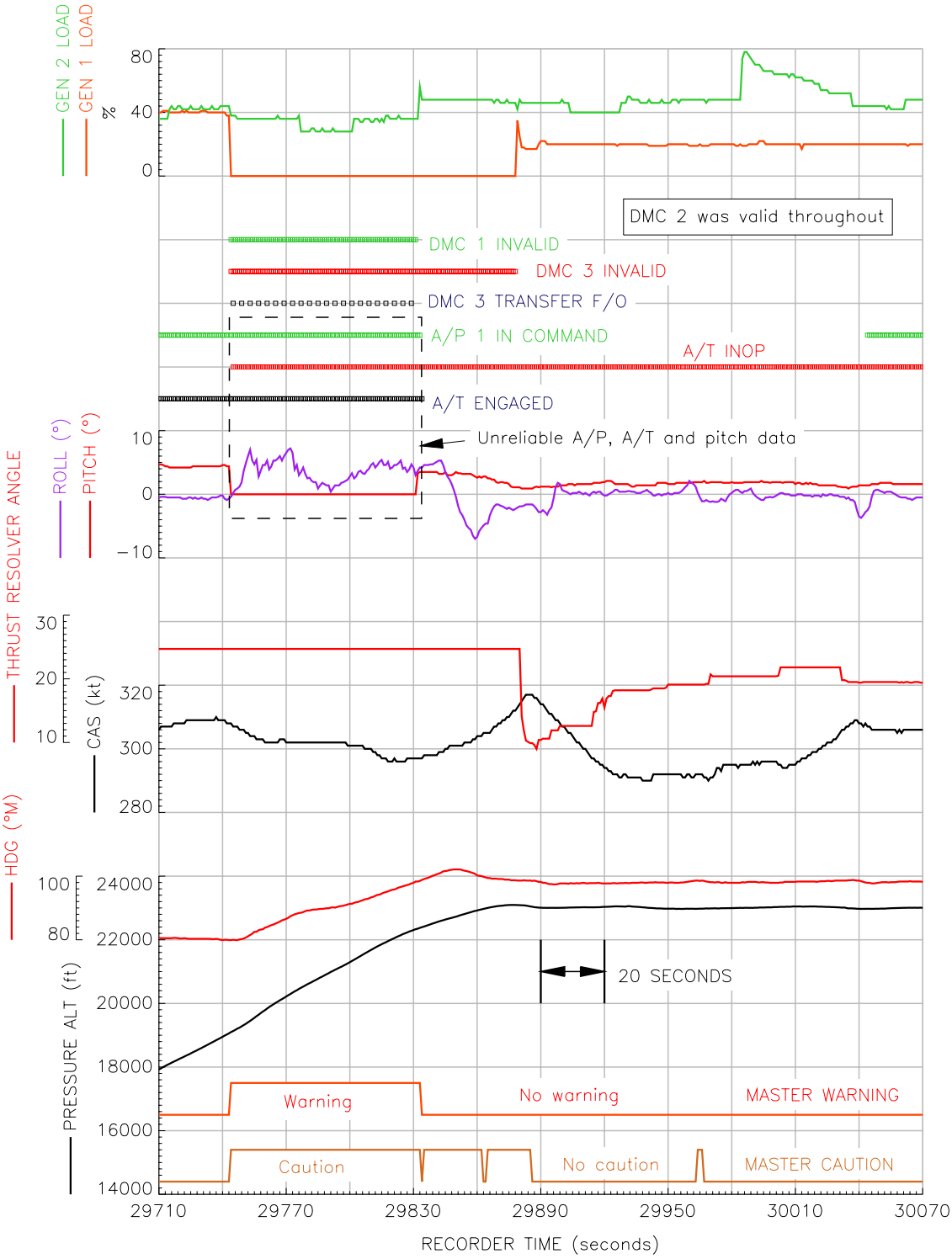

Figure 10

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.

A P Simmons
Principal Inspector of Air Accidents
Air Accidents Investigation Branch
Department for Transport
December 2007