AIRCRAFT ACCIDENT REPORT 4/2009

Air Accidents Investigation Branch

Department for Transport

Report on the serious incident to Airbus A319-111, registration G-EZAC near Nantes, France on 15 September 2006

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

The sole objective of the investigation of an accident or incident under these Regulations shall be the prevention of accidents and incidents. It shall not be the purpose of such an investigation to apportion blame or liability.

1.6.3.5 Electrical Power Distribution

The distribution system (Figure 7) consists of AC and DC busbars and sub-busbars. It includes the AC Essential busbar (AC ESS), normally powered from AC BUS 1; two DC Main busbars (DC BUS 1 and DC BUS 2), normally powered from AC BUS 1 and AC BUS 2 respectively via the TRs; and a DC Essential busbar (DC ESS), normally powered from DC BUS 1 via a DC Battery busbar (DC BAT). The AC and DC Essential busbars each supply an associated ESS SHED busbar. A HOT busbar is supplied directly from each battery.

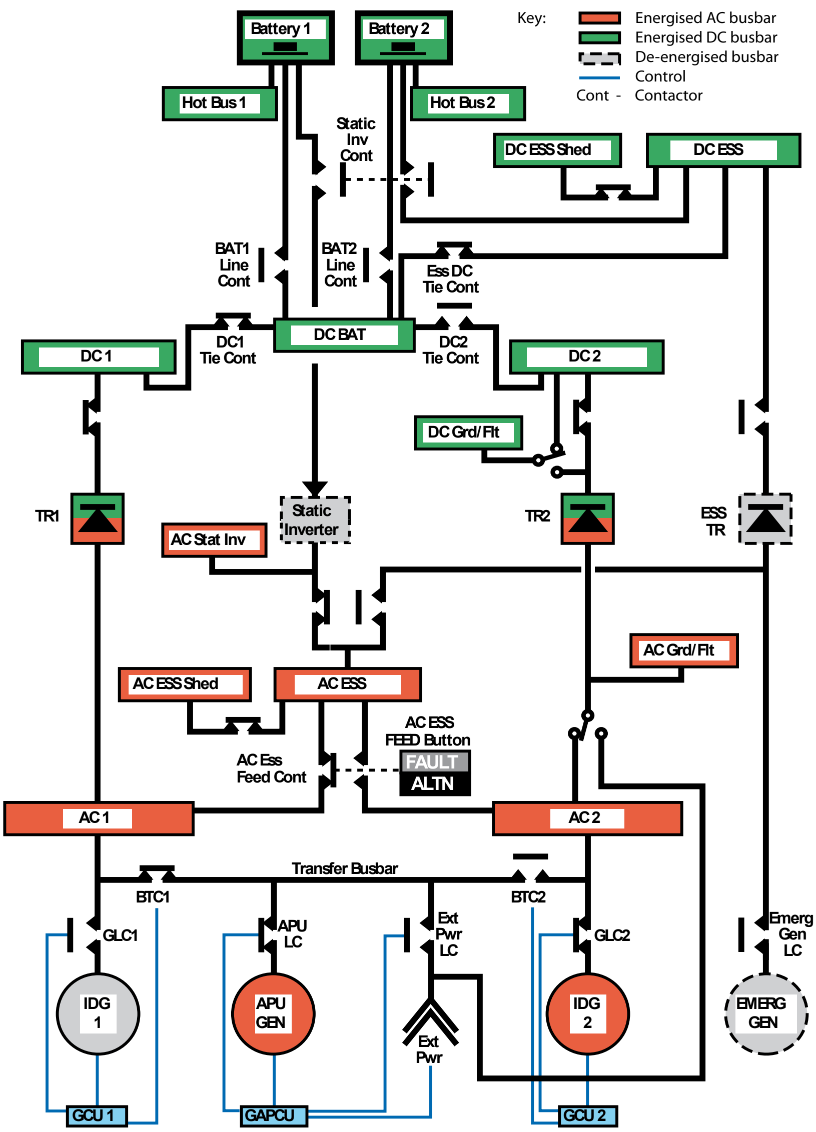

Figure 7

EPGS Distribution System - G-EZAC Dispatch Configuration shown

Thus, loss of AC BUS 1 results in loss of the AC ESS busbar, and also the loss of the AC ESS SHED busbar. As loss of AC BUS 1 de-powers TR 1, it also causes loss of the DC BUS 1 as well as loss of the DC ESS and DC ESS SHED busbars (Figure 8). After five seconds DC BUS 1 is automatically transferred to feed from DC BUS 2 via the DC BAT busbar, but it does not supply the DC ESS busbar.

Reinstatement of the AC ESS busbar and its sub-busbars following the loss of AC BUS 1 is automatic on newer Airbus types. On A320-series aircraft, however, this operation must be performed manually and appears as an ECAM

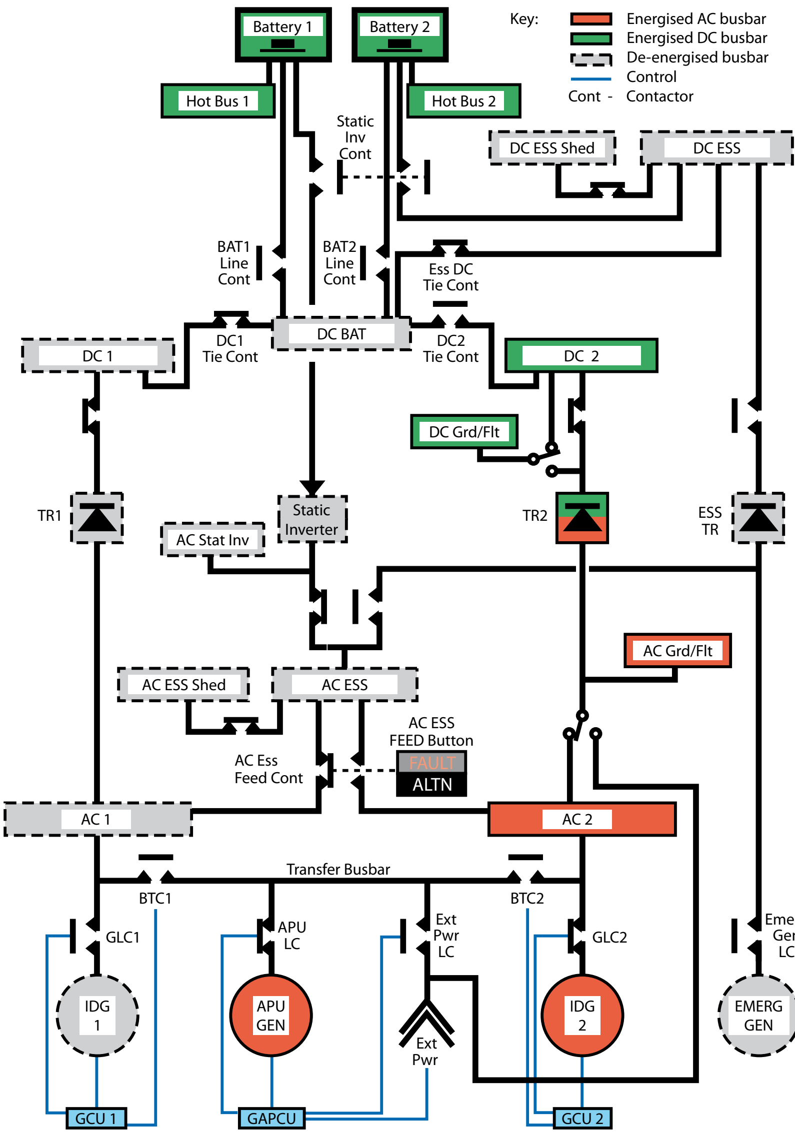

Figure 8

EPGS Distribution System – Immediately After Failure action item following an electrical failure. Loss of the AC ESS busbar should cause the Master Caution to trigger, an ‘AC ESS FAULT’ warning message to appear on the ECAM DU and an amber ‘FAULT’ caption to illuminate in the ‘AC ESS FEED’ push-button selector switch on the EPGS control panel. Data from Airbus suggests that, following AC BUS 1 failure, a flight crew will typically take, on average, about one minute to restore power to the AC ESS busbar by selecting the AC ESS FEED switch. The crew of G-EZAC reported that they performed this action a number of times, but it did not result in power being restored to the AC ESS busbar.

Pushing the AC ESS FEED push-button should operate two changeover contactors to transfer supply of the AC ESS busbar to AC BUS 2 and to illuminate a white ‘ALTN’ caption in the push-button. This action should re-power the AC ESS and AC ESS SHED busbars. Additionally, the system should automatically reconfigure to power the DC ESS busbar from the AC ESS busbar via the Essential TR, thereby also restoring the DC ESS SHED busbar. Return of the normal feed to the AC ESS and DC ESS busbars would require reselection of the AC ESS FEED switch.

TR 1 registers the loss of its input power as a fault, which remains latched after TR 1 is re-energised. TR 1 can be reset using the flight deck MCDU, to resupply the DC BUS 1 busbar from AC BUS 1 but this can only be performed when the aircraft is on the ground.

1.6.3.6 GCU - Generator Control Unit

The GCUs are digital microprocessor-based controllers, each consisting of an equipment box rack-mounted in the aircraft’s forward electronics bay. The unit contains electrical and electronic components on five printed circuit boards. Its primary power supply is from a Permanent Magnet Generator (PMG) which forms the initial stage of the IDG. It is also fed with a backup power supply from the respective 28V DC Battery busbar.

The GCU functions include providing control and protection by monitoring and regulating both the output of the associated IDG and the operation of a number of the electrical distribution system contactors. It also stores information on electrical system status and feeds it to aircraft systems, and performs system testing and self-monitoring. G-EZAC’s GCU software at the time of the incident was at Standard 5.1.

The EEPGS GCU model fitted to G-EZAC is also used on the other Airbus A320-series aircraft types and on A330 and A340-series aircraft. Different software standards for the different aircraft models are determined by programming of the connector pins. The GCU is a 'Line-Replaceable Unit' (LRU), meaning that it is designed to enable easy replacement in the event of a suspected problem.

The GCU maintains the IDG output voltage and frequency within limits by modulating, respectively, the IDG field current and a servo valve in the constant-speed drive. It also performs 24 IDG and electrical system protection functions in the event of abnormalities, primarily by means of three relays within the GCU:

- A Generator Control Relay (GCR), controlling the generator excitation
- A Power Ready Relay (PRR), controlling the GLC
- A Servo Valve Relay (SVR), controlling the IDG rotational speed

One of the GCU's functions is to monitor the current in each phase at various points in the electrical system, as sensed by means of Current Transformers (CTs). These are effectively ammeters. Each of the three output leads (3-Phase output) from the IDG passes through a coil in the CT, inducing a secondary current in the coil. CTs are located, among other points, within the IDG at the IDG output and at the GLC input (Figure 9), providing 'IDG Current' and 'Line Current' measurement signals respectively. Within the GCU each CT signal is converted to a voltage, amplified and converted to a digital signal which is compared with a reference signal. The CT signals are used for a number of the protection functions.

1.6.3.7 GCU Differential Protection

For one of its protection functions, known as 'Differential Protection' (DP), the GCU compares the IDG current with the line current in each phase, as sensed by the CTs. An excessive difference is assumed to be due to a short circuit, either between phases or to earth. The threshold is 50±10 A difference persisting for at least 80 milliseconds (ms).

If the threshold is exceeded, the GCU reacts by de-exciting the IDG and tripping the PRR, thus causing the GLC to open. A Built-In Test Equipment (BITE) message 'FC [Fault Code] 131 IDG GEN CT/GCU' is generated, signifying that a DP trip has occurred. In the normal situation with the electrical networks

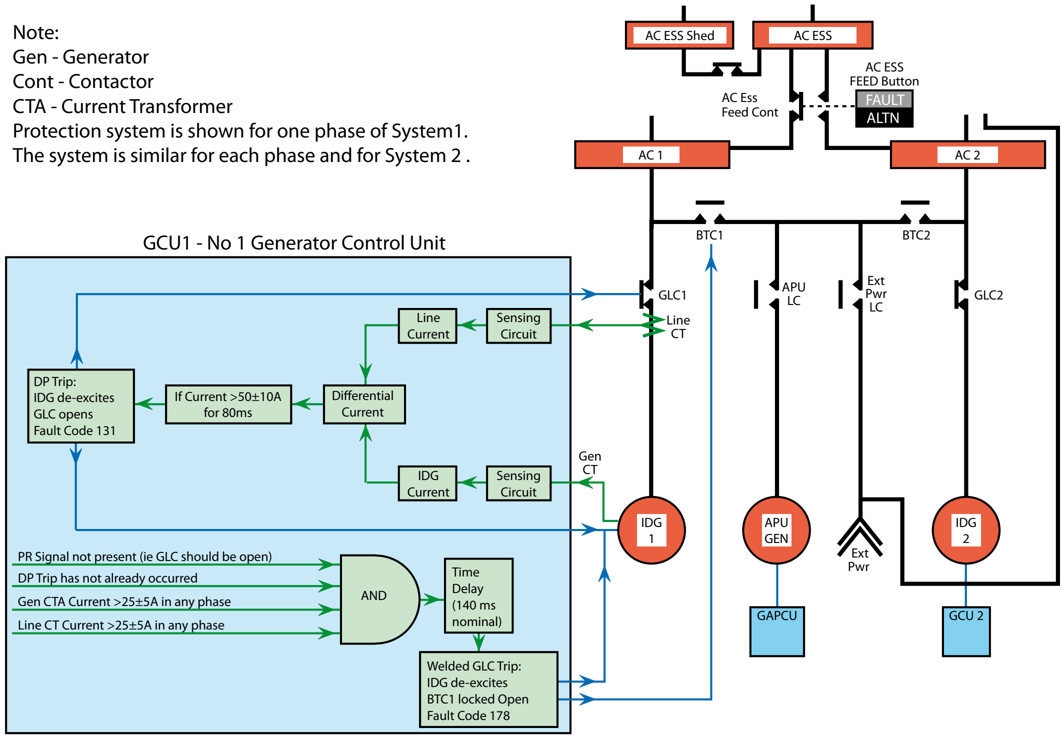

Figure 9

Differential and Welded GLC Protection Schematic

being supplied by the two IDGs, the loss of output from the affected IDG causes the BTCs to close automatically via relay logic, and the remaining online IDG then feeds both AC Main busbars. If the APU generator is online, only the BTC on the affected side closes, to replace the lost IDG supply. In either case, the automatic switching of power sources means that there should be no loss of electrical power to the aircraft's systems.

1.6.3.8 GCU Welded GLC Protection

Another function, known as 'GLC Failure Protection' or 'Welded GLC Protection' aims to ensure that the GLC has, in fact, opened when signalled to do so. In this case the GCU monitors only the IDG CT signal. If a significant current is sensed in any phase when the signal to activate the PRR is absent and a DP has not been triggered, the GCU assumes that the GLC has erroneously remained closed and therefore de-excites the IDG. Additionally, the GCU locks out the BTC on the same side in order to prevent it from closing and potentially creating a hazard by allowing other power sources to motor the IDG through the apparently closed GLC contacts. A BITE message 'FC 178 GLC' is registered in the GCU Non-Volatile Memory (NVM), signifying that a Welded GLC Protection trip has occurred.

The IDG CT current threshold for this function is more than 25±5 A for 140 ms (-10/+20 ms).

As this function is intended to protect against failure of the GLC contacts to open, it remains in effect after the associated generator has been selected off.

1.6.3.9 Ground Power/APU Generator Control Unit

The GAPCU is a similar unit to the GCU, providing monitoring, control, protection, testing, status and fault reporting functions for the APU generator and ground power sources. In addition, the GAPCU acts as the BITE interface for the entire EPGS.

1.6.3.10 System Test and Fault Monitoring

The GCUs and the GAPCU incorporate BITE, with operational monitoring, fault isolation and maintenance test functions for the EPGS. The GAPCU co-ordinates these activities. It receives data on EPGS status from the GCUs for display on the ECAM and also forms the EPGS BITE interface, interrogating and commanding the GCUs for BITE purposes.

The GCUs and GAPCU each perform a self-test when initially powered up and then continuously monitor themselves and associated parts of the system. If a fault is detected that would result in a protective trip, the unit checks its fault sensing system, in an attempt to isolate the fault, by stimulating the sense circuitry associated with the trip and checking the response. If the response is as expected, the system judges the fault to be external to the controller. The unit records data on the fault in its NVM. The GAPCU reads the faults recorded by the GCUs and passes them, together with its own recorded faults, to the Centralised Fault Display System (CFDS). The CFDS is primarily a troubleshooting aid for maintenance personnel. Details of the faults can be read from the Post Flight Report (PFR), which is generated by the CFDS.

Additionally, in the event of a protective trip, a 'snapshot' facility enables the GCU or GAPCU to record detailed information on relevant parameters, known as Trouble-Shooting Data (TSD). The unit captures the TSD within the microprocessor cycle in which the fault is sensed, before activating any associated protection function, and stores it in its memory. In the case of a DP trip, the current after the protection has operated is also recorded.

For maintenance purposes, the units can be commanded on the ground to perform a self-test, when the associated generator is not running. The GAPCU transmits the test command to the GCUs and passes the results back to the CFDS. Reports on the status of aircraft systems, including a PFR and Previous Legs Reports, can be printed out to assist maintenance operations.

1.6.4 Other Relevant Aircraft Systems

1.6.4.1 Laptop tool

The aircraft was equipped with two laptop computers for the pilots to be able to access information from the FCOM. Paper copies of the FCOM were not available but a paper copy QRH was available.

1.6.4.2 APU

The left engine fuel feed line supplies the APU. The required pressure is normally available from tank pumps. If pressure is not available (aircraft on battery power only or pumps are off) the APU fuel pump will start automatically.

1.6.5 Minimum Equipment

The aircraft manufacturer's Master Minimum Equipment List (MMEL) specifies the non-critical aircraft equipment that is permitted to be unserviceable when the aircraft is dispatched, together with any associated operational limitations and the maximum allowable period before rectification is required. From the MMEL, each operator typically generates an individual MEL, which can be more restrictive than the MMEL, but never less so.

The A320-series MMEL permitted dispatch of the aircraft for non-Extended Twin Operations (ETOPS) flights for a maximum of 10 days with one IDG, GCU and/or GLC inoperative, provided the APU generator was online and used throughout the flight and provided the rest of the EPGS was operating normally. G-EZAC's operator had included the above dispatch allowance in its MEL. The conditions specified in the FCOM were as follows:

> *'1) APU and AC auxiliary generation are operative and used throughout the flight*
>
> *2) APU fuel pump is operative*
>
> *3) All busses can be powered*
>
> *4) Indications and warnings for the remaining AC main generation and the AC auxiliary generation are operative*
>
> *5) Flight altitude is limited to 33,500 ft*
>
> *6) Galley automatic shedding is operative'*

An Operational Procedure detailing a pre-flight check of the EPGS aimed at ensuring that the conditions were met was provided in a subsection of the MEL. However, the instructions on how to perform the required test of the APU fuel pump were elsewhere in the FCOM, which was not clearly evident to the crew. Therefore this part of the procedure was not carried out before G-EZAC's departure from Alicante. The procedure did not require a check of the transfer of the AC ESS busbar feed from AC BUS 1 to AC BUS 2 using the AC ESS FEED switch.

Both the MMEL and operator's MEL provisions were irrespective of the type of fault that had led to the unserviceability. There was no requirement or recommendation for any checks aimed at determining the cause of an IDG, GCU or GLC fault, prior to dispatch with one or more of them inoperative.

1.6.6 Effects on aircraft systems of AC BUS 1 and AC ESS busbar loss

1.6.6.1 General

Loss of AC BUS 1, prior to transfer of the AC ESS busbar to AC BUS 2, results in a very large number of aircraft systems effects, most of which are summarised in Appendix 1.

As well as the effects given in Appendix 1, loss of the AC BUS 1 and AC ESS busbars also results in loss of all the annunciator lights powered by the de-energised busbars. Annunciator lights powered by AC BUS 2 or by the other busbars that remain energised should still be operative.

The more significant systems affected by loss of AC BUS 1, AC ESS and their sub-busbars are described in the following sections.

1.6.6.2 Electronic Instrument System

Loss of the AC BUS 1 and AC ESS busbars causes the loss of power supplies to the captain's PFD and ND and the upper ECAM display and thus blanking of these displays.

1.6.6.3 Hydraulic system

A320-series aircraft have three hydraulic systems, designated as Blue, Green and Yellow. The Blue system is normally pressurised by an electrically-powered pump supplied from AC BUS 1. The Blue system powers specific primary and secondary flight control surfaces, in conjunction with Green and Yellow systems. In certain failure situations the Blue system can be powered from a pump driven by the RAT. If the RAT is not operating, loss of AC BUS 1 will cause depressurisation of the Blue hydraulic system.

1.6.6.4 Air Data and Inertial Reference System

The aircraft's ADIRS utilises three Air Data and Inertial Reference Units (ADIRU) to determine flight parameters for use by multiple aircraft systems. The ADIRU power supply busbars are AC ESS for No 1, AC BUS 2 for No 2 and AC BUS 1 for No 3. Thus de-energisation of the AC BUS 1 and AC ESS busbars causes loss of the No 1 and No 3 ADIRUs.

1.6.6.5 Flight controls

Primary and secondary flight control surfaces are controlled via a number of flight control computers which receive data on aircraft behaviour from the ADIRS.

The normal flight control laws use normal acceleration and roll rate as basic parameters and provide a number of features, including stability, automatic longitudinal trimming, Dutch roll damping, turn coordination and engine failure compensation. They also provide protection against extreme attitudes, excessive load factor, overspeed and stall. In the event of loss of two or more ADIRUs the system reverts to alternative control laws, such as 'pitch alternate' and 'roll direct', under which many of the automatic and protection features are lost.

Loss of the AC BUS 1 and AC ESS busbars de-energises a number of the flight control computers and actuator electric motors, reducing the level of redundancy for both primary and secondary flight controls. The concurrent loss of two ADIRUs resulting from the busbar losses would cause reversion to the alternate control laws. Depressurisation of the Blue hydraulic system renders the No 3 ground spoiler on each wing inoperative.

1.6.6.6 Landing gear

Normal landing gear actuation uses the Green hydraulic system. A safety valve automatically isolates the hydraulic supply to the gear when the calibrated airspeed, as determined by the ADIRS, exceeds 260 kt. The airspeed data is supplied by ADIRUs 1 and 3.

Loss of both airspeed data sources due to loss of the power supplies to ADIRUs 1 and 3 will also cause the safety valve to close, with the effect that the landing gear cannot be retracted and must be lowered by gravity using the emergency extension system.

1.6.6.7 Cabin pressurisation

Cabin pressurisation is normally controlled and monitored automatically by two independent systems, each with a Cabin Pressure Controller (CPC). De-energisation of the AC BUS 1 and AC ESS busbars prevents CPC 1 and CPC 2 from operating, because of the loss of power and loss of ADIRU data. Cabin pressurisation would then need to be controlled manually by the crew. The excess cabin altitude warning system would still be operational.

1.6.6.8 Oxygen systems

The passenger oxygen system provides oxygen supply via masks normally contained in the overhead panels. The masks automatically deploy if the cabin pressure altitude exceeds 14,000 ft. The system operates via a sequence of relays and a pressure switch, powered from the DC ESS busbar. The relays allow supply of power from the AC ESS SHED busbar to an electrical latch assembly in the overhead panels which releases the oxygen masks. A manual release system operates in the same way as the automatic system, except that the pressure switch is bypassed.

Loss of the AC BUS 1 and AC ESS busbars causes loss of both DC ESS and AC ESS SHED busbars and thus prohibits the release of the passenger oxygen masks, either automatically or manually. The flight crew oxygen system is unaffected.

1.6.6.9 VHF radio

The VHF radio communication system comprises the ACPs, Audio Management Units (AMU), the transceivers and the RMPs. 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 backup 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 should fail, the crew can switch to 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.

G-EZAC was fitted with upgraded digital AMUs. Unlike earlier versions, both audio cards in all three AMUs rely on supplies from the DC ESS busbar. The unit ceases to function when both audio cards are unpowered. Loss of the DC ESS busbar as a result of AC BUS 1 and AC ESS busbar loss thus renders all three VHF radios inoperative. Given this finding, Airbus has stated:

> *'In the light of this [G-EZAC's] event Airbus is evaluating if the power supply of the digital AMU need to be modified'*

1.6.6.10 ATC transponder

The aircraft was equipped with two independent transponder channels, designated ATC 1 and ATC 2[5]. ATC 1 is powered from the AC ESS SHED BUS and ATC 2 from the AC BUS 2 busbar. Loss of the AC BUS 1 and AC ESS busbars thus renders ATC 1 inoperative. ATC 2 should function after being manually selected and did so in this case. However, several minutes had elapsed before the crew made the ATC 2 selection, during which period G-EZAC was not visible on the Brest ATCC radar screens.

[5] 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.

1.6.6.11 Traffic Alert and Collision Avoidance System

The ATC 1 transponder provides data to the TCAS. This communicates with other similarly-equipped aircraft in the vicinity to provide an alert to both crews of a possible flight path conflict and, if necessary, to advise manoeuvres to avoid a collision.

Loss of this transponder also causes the TCAS to be inoperative. The TCAS is powered from AC BUS 1 and is thus disabled if this busbar de-energises.

1.6.6.12 Enhanced Ground Proximity Warning System

The aircraft was fitted with an Enhanced Ground Proximity Warning System (EGPWS) that provides alerts and warnings aimed at preventing the aircraft from colliding with terrain. The system was powered from the AC BUS 1 busbar and is thus disabled if this busbar de-energises.

1.7 Meteorological information

The pilots reported that they were flying in VMC at the time of the event. Following the loss of electrical power the pilots were not able to obtain any further meteorological reports. They were able to maintain VMC for most of the remainder of the flight.

The 0950 METAR for Bristol, received en route through the ACARS prior to the incident, was as follows:

> *'Surface wind from 020º at 14 kt, visibility more than 10 km, few cloud at 1,000 ft, temperature 13ºC, dewpoint 11ºC and QNH*[6] *1012 mb'*

Weather information for a number of other airfields in the UK had also been received through ACARS prior to the incident and information for airfields in France was received in the pre-flight briefing documentation.

1.8 Aids to navigation

Not applicable.

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

1.9 Communications

1.9.1 Air Traffic Control

1.9.1.1 Incident flight

G-EZAC made first contact with Brest ATCC at 1051 hrs and reported level at FL 320. The co-pilot inadvertently used the incorrect callsign EZY6078 instead of EZY6074. The Brest controller queried the callsign and correct contact was then established. The aircraft was identified on the radar screens transmitting transponder code 5376.

At 1053 hrs the radar controller noticed that the Secondary Surveillance Radar (SSR)[7] returns from EZY6074 had disappeared, leaving only trace information visible, and then nothing (primary radar returns were not displayed on the Brest radar screens). He made several radio calls to try to contact the aircraft but received no reply. EZY6074 reappeared on their radar screens some 10 minutes later, but the controllers were unable to re-establish radio contact with the aircraft.

Bristol ATC first became aware of the emergency traffic inbound at 1110 hrs when they were called by ATC at West Drayton, who advised that EZY6074 was over the south coast of England in a descent, but not in radio contact.

Bristol ATC took action to notify all the responsible authorities to ensure the airport was prepared to accept the emergency aircraft. A full emergency was declared by the airport at 1116 hrs. All air traffic movements at Bristol Airport were suspended as the aircraft approached. When the aircraft was established on final approach, the tower controller broadcasted blind transmissions giving landing clearance and surface wind information.

1.9.1.2 Reports from Brest ATCC radar controllers

The incident occurred during the period of a shift change at Brest ATCC, which took place at 1100 hrs. After the incident, reports were received from the Brest radar controllers who covered the period from when EZY6074 disappeared from the radar screens until the time it reappeared.

The first radar controller noticed the disappearance of EZY6074 from his

[7] Primary radar systems monitor aircraft position by monitoring reflected radio signals to determine a range and bearing from the radar head. SSR is more advanced and allows additional aircraft parameters such as altitude, speed and rates of descent to be seen by ATC. This is achieved by the aircraft transmitting parameters via a transponder which is interrogated by the ATC ground station.

screen about 10 minutes before the shift change was due. He looked across at another screen and noticed that it had also disappeared from there. He made several radio calls to try to contact the aircraft, but without success.

The strategic controller realised that both radar and radio contact with EZY6074 had been lost. Attempts were then made to contact the aircraft on 121.5 MHz directly and by asking another easyJet aircraft to try on the company frequency, but these proved unsuccessful. The ATC personnel now realised they had no information as to the whereabouts of the aircraft and feared that it might have suffered a catastrophic event.

At 1056 hrs a westbound aircraft, callsign AAL63, checked in at FL 320 and was acknowledged by Brest ATCC. The radar controller then realised that if EZY6074 was continuing along its assigned north-north-westerly track at FL 320, there was a danger of it conflicting with AAL63, routing from east to west at the same flight level. He called AAL63 and asked if they could see the missing aircraft on their TCAS. After conferring with his replacement controller, as a precaution he decided to instruct AAL63 to descend to FL 310.

The shift change went ahead despite the complication of the apparently missing aircraft and the resultant inability of one shift to carry out a complete handover of information to the other. The oncoming radar controller was anxious to ensure that the AAL63 started a descent without delay and issued a second instruction to the aircraft to descend. AAL63 then started a descent and a few moments later one of the flight crew advised that they had seen an "easyJet 737" pass overhead northbound, but it was not visible on their TCAS display.

The radar controllers were relieved that the EZY6074 had been found, but also alarmed that it had come so close to another aircraft. A few moments later, the secondary radar signal from EZY6074 reappeared and one minute later the 'squawk' code changed to 7700, the emergency code.

1.9.2 ACARS

On the outbound flight from Stansted to Alicante the commander contacted the operator's Maintrol facility to advise of the generator failure. A copy of these communications was available for the investigation.

An attempt was made to contact G-EZAC by the operator following the loss of communication but this proved unsuccessful.

1.9.3 Telephone

As G-EZAC approached Bristol the commander attempted to communicate directly with Bristol ATC by mobile telephone. However, he was unable to obtain a signal even at low altitude.

In August 2006, NATS, the UK national air traffic service provider, issued a safety notice regarding the use of satellite phones in case of Radio Telephony (RTF) failure as a result of a study which showed a marked increase in the number of radio failure incidents in UK airspace. The safety notice advised that with the current heightened awareness of airborne security, if ATC is unable to establish contact with an aircraft with an RTF failure it could lead to the aircraft's interception by the UK Ministry of Defence. The notice included details of allocated airborne telephone numbers for aircraft to call in the event of loss of all other means of communication with ATC. G-EZAC was not equipped with a satellite phone.

1.9.4 Procedures for loss of radio communication

Radio failure procedures for aircraft in UK airspace are specified in the UK Aeronautical Information Publication (AIP), section ENR 1.1.3. They were also available on the aircraft in a commercial booklet. In summary, in the event of loss of radio communication, ATC will expect an Instrument Flight Rules (IFR) flight to carry out the notified instrument approach procedure as specified for the designated navigational aid and, if possible, land within 30 minutes of the Estimated Arrival Time (EAT).

1.10 Aerodrome information

Bristol Airport has a single bi-directional runway orientated 09/27. Runway 09 is 2,011 m long and 45 m wide. The Landing Distance Available (LDA) is 1,938 m and the runway has a net downslope of 0.15%. The touchdown elevation is 613 ft amsl.

1.11 Flight Recorders

The aircraft was fitted with a solid state Cockpit Voice Recorder (CVR), Flight Data Recorder (FDR) and Quick Access Recorder (QAR). Data from all three devices was downloaded and used together with data from the aircraft's CFDS.

1.11.1 CVR

The CVR was a two-hour, four-channel recorder. Power supply to the CVR was from the AC ESS SHED busbar. The recording captured the end of the previous flight and one hour and 42 minutes of the incident flight.

As it was powered by the AC ESS SHED busbar, the CVR ceased recording at the time of the incident. Recording restarted once the aircraft was on the ground and the electrical power was recovered. Therefore no audio information was available for the incident.

1.11.2 FDR

The FDR recorded just over 26 hours of operation and, as it was powered from AC BUS 2, it remained powered throughout the flight. The QAR, which had the same power source, also remained available.

Data recorded by the FDR was collected from the various aircraft systems via the Flight Data Interface Management Unit (FDIMU). The FDIMU was also powered by AC BUS 2, so data flow was maintained throughout the flight.

As electrical system parameters were recorded by the FDR every four seconds, an electrical transient or instantaneous power loss may not have been captured by the FDR. It is possible for contactors to cycle more than once within a four second period and the FDR data must therefore be interpreted with this in mind.

A number of parameters which would have been useful for this investigation were not recorded by the FDR. These include AC and DC supply voltages, AC ESS FEED push-button switch position and APU and RAT operation parameters. Additionally, no cabin pressurisation parameters, other than the excess cabin altitude warning, were recorded.

1.11.3 Pre-flight MEL procedure

The CVR captured the pre-flight MEL Operational Procedure performed by the flight crew prior to dispatch with IDG 1 inoperative. This was time-aligned with the FDR to confirm the operation of the electrical system.

Engine start was at 0911 hrs. The opening or closing of BTC 2 and GLC 2 recorded on the FDR coincided with a 'clunk' noise recorded on the Cockpit Area Microphone (CAM). The MEL procedure was carried out and the response of the electrical contactors was as expected.

1.11.4 Incident flight from Alicante to Bristol

The aircraft departed Alicante with the APU generator supplying power to AC BUS 1. GLC 1 was open, BTC 1 closed, BTC 2 open and GLC 2 closed. As the aircraft approached northern France at FL 320 and an indicated airspeed of 277 kt, autothrust and autopilot were engaged and all AC and DC busbars were powered.

At 1052:41 hrs, the CVR ceased recording and the FDR recorded BTC 1 opening and loss of the AC BUS 1, AC ESS and DC ESS busbars.

The FDR recorded the status of the AC BUS 1-AC ESS contactor and the AC BUS 2-AC ESS contactor as separate parameters. The AC BUS 1-AC ESS contactor opened at the time of the event and remained open for the rest of the flight. No further change to either changeover contactor was recorded and the AC BUS 1, AC ESS and DC ESS busbars were recorded as unpowered for the remainder of the flight.

At the time of the loss of AC BUS 1, the TR 1 contactor was no longer supplied and therefore opened, which would have led to the loss of supply to DC BUS 1 (Figure 8, page 19). However, no loss of DC BUS 1 was recorded on the FDR, possibly due to the parameter sampling rate. At the same time, the DC BUS 1 Tie contactor opened and the DC BUS 2 Tie contactor closed. The DC BUS 1 Tie contactor then closed, powering DC BUS 1 via DC BUS 2.

1.11.4.1 Effects on aircraft systems

After the loss of power, the recorded status of the aircraft systems was consistent with the loss of power supply to the AC BUS 1, AC ESS and DC ESS busbars (Appendix 1).

The recorded data also showed a switch from the 'normal' flight control law to 'pitch alternate law' and 'roll direct law'. After the autopilot disconnection, the control inputs for the remainder of the flight were made exclusively via the first officer's sidestick.

Recorded data for hydraulic pressures became invalid after the loss of power because the hydraulic pressure sensors were powered by the DC ESS SHED busbar. The loss of these sensors also meant that the ECAM display of hydraulic pressure would no longer be available. Discrete data for hydraulic pressures was successfully recorded and indicated 'low Blue system hydraulic pressure' eight seconds after the loss of AC BUS 1. The FDR also recorded a 'loss of Spoiler 3 availability' and the loss of Blue hydraulic system control of the ailerons and elevators.

1.11.4.2 No 2 Bus Tie Contactor operation

Prior to the event, BTC 2 was open but 51 seconds after the loss of AC BUS 1, the FDR recorded a BTC 2 closure. According to the aircraft manufacturer, in this electrical configuration, the only reason for BTC 2 to close was if the APU GLC had opened. The APU GLC position was not recorded so this cannot be confirmed.

Two minutes and 20 seconds later, BTC 2 reopened, suggesting that the APU GLC had closed. This BTC 2 behaviour was repeated on two further occasions over around seven minutes. Finally, BTC 2 remained open until after touchdown in Bristol.

1.11.5 Radar recordings

The radar data analysed in the investigation was obtained from NATS, the UK air traffic control services provider. Data was recovered from the Jersey, Burrington and Clee Hill radar heads. When the event occurred, the radar recordings showed a loss of SSR (Figure 10), but G-EZAC was still visible on primary radar[8].

The recorded radar data also showed the westbound tracking AAL63 in the vicinity of G-EZAC at FL 320. AAL63 began its descent from FL 320 at 1101:17 hrs. Analysis of the data indicated that EZY6074 crossed the path of AAL63 2.86 nm in front of it, heading north-north-west. At this time, AAL63, which was tracking to the west towards EZY6074, was around 600 ft below EZY6074's level, having commenced its descent 40 seconds earlier. AAL63 continued its descent and arrived at the point of intersection of the two aircrafts' tracks at 1102:16 hrs, at around FL 310, 19 seconds after EZY6074 had passed by. At this time EZY6074 was 2.67 nm to the north. This was the closest recorded separation between the two aircraft.

1.11.6 Flight Recorder improvements

1.11.6.1 Recorder Independent Power Supply

In March 2003, the European Organisation for Civil Aviation Equipment (EUROCAE) issued ED112, defining a *'Minimum Operational Performance*

[8] Primary radar returns were recorded from Burrington radar as Jersey only has secondary radar.

Google Earth™ mapping service/CNES/Spot image, Teleatlas, Europa Technologies, NASA

Figure 10

G-EZAC Secondary Radar Recording

Specification (MOPS) for Crash Protected Airborne Recorder Systems'. Within ED112 is the minimum specification for a Recorder Independent Power Supply (RIPS). RIPS is a device capable of providing the CVR with a backup power supply, independent of the aircraft electrical system. The purpose of the RIPS is to allow for continued operation for 10 minutes in all cases where electrical power to the recorder is removed.

The International Civil Aviation Organisation (ICAO) Flight Recorder Panel has submitted a number of recommendations for modifications to ICAO Annex 6 (Operation of Aircraft) which included the implementation of RIPS. The current recommendations for this aircraft category[9] are:

- to *require* implementation of RIPS for all new aircraft and new aircraft types which are fitted with a CVR, built after 1 January 2016.
- to *recommend* that all in-service aircraft fitted with a CVR be fitted with a RIPS from 1 January 2016

[9] Fixed-wing commercial air transport aircraft with a Maximum Takeoff Weight (MTOW) in excess of 5,700 kg.

These recommendations were drafted based on studies and flight recorder specialist' experience, and are currently being assessed by ICAO.

1.11.6.2 Cockpit Image Recording

ED112 also defines a minimum specification for aircraft required to carry an image recording system. Currently no aircraft are required to carry such a system. The UK CAA has conducted a trial to establish the effectiveness of airborne image recorders which is reported in CAP 762. One of the conclusions of this report was that '*image recorder systems provide images of sufficient resolution to enable investigators to identify both missing data and data fail flags*'. Cockpit image recording is also the subject of the ICAO Flight Recorder Panel and, as for RIPS, recommendations have been submitted to ICAO for updates to Annex 6. The current drafts for this aircraft category[10] are:

> *'All aeroplanes of a maximum take-off mass of over 5700 kg for which the individual certificate of airworthiness is first issued on or after 1 January 2016 should be equipped with a Class A AIR[11] capable of capturing data supplemental to conventional CVR and FDR flight recorders*
>
> *From 1 January 2018 all aeroplanes of a maximum take-off mass of over 5700 kg should be equipped with a Class A AIR capable to capture data supplemental to conventional CVR and FDR flight recorders.'*

Both of these requested changes are 'recommended' items which means that compliance is not mandatory.

The AAIB report into the G-EUOB incident made the following safety recommendation (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.*

[10] Fixed-wing commercial air transport aircraft with a Maximum Takeoff Weight (MTOW) in excess of 5,700 kg.
[11] A Class A Aircraft Image Recorder (AIR) is defined as one which is required to capture the general cockpit area including data supplemental to conventional flight recorders.

The ICAO formally responded to the Safety Recommendation on 25 June 2008, stating that: 'The Air Navigation Commission (ANC) has tasked the Flight Recorder Panel to develop Standards and Recommended Practices (SARPs) on requirement for airborne image recorders. The proposed SARPs are planned to be reviewed towards the end of 2008.'

1.12 Aircraft Examination

1.12.1 Initial

The flight crew and an operator's technician who attended G-EZAC provided initial reports on the aircraft's status after its arrival at Bristol. They indicated that it was not possible to bring the APU generator online until the battery switches had been cycled OFF and ON. A GPU was subsequently connected and took over supply of the aircraft electrical system in the normal way.

1.12.2 Fault and Troubleshooting Data

CFDS Post Flight Reports obtained during the investigation showed the following fault messages relevant to the EPGS on the day of the incident:

Time hrs	Phase of Operation	Fault Message	Fault Message Meaning
0227	Engine ground run	IDG1 (E1-4000XU) GEN CT/ GCU1 (1XU1)	Fault detected by GCU1 IDG CT
0539	Stansted-Alicante leg (start 0514 hrs stop 0743 hrs)	IDG1 (E1-4000XU) GEN CT/ GCU1 (1XU1)	Fault detected by GCU1 IDG CT
1052	Alicante-Bristol leg (start 0927 hrs stop 1133 hrs)	GLC1 (9XU1)	Fault on GCU1

The items in parentheses are the aircraft manufacturer's circuit component identifiers, known as Functional Item Numbers (FINs).

TSD retrieved from GCU1's NVM provided the following information:

Leg	Current Transformer	Current sensed by Current Transformers (amp)		
		Phase A	Phase B	Phase C
Stansted-Alicante	IDG CT	80.8	0	80.8
	Line CT	80.8	90.9	80.8
Alicante-Bristol	IDG CT	0	20.2	0
	Line CT	0	0	0

Thus, the information indicated that during the first flight leg a difference of approximately 91A between the IDG and Line current signals for Phase B of the No 1 system had been sensed. This would be expected to cause activation of the Differential Protection function (threshold 50±10A) and to trigger the IDG 1 fault that was recorded. During the incident flight, with No 1 generator switched off, an IDG 1 Phase B current of around 20A was sensed. This would be expected to trigger a Welded GLC Protection (threshold 25±5A) and the GLC 1 fault that was registered.

1.12.3 Aircraft Inspection

An AAIB-supervised examination of the aircraft commenced on the day of the incident and a number of ground checks were carried out over the following three days, with the operator's assistance. An electrical system specialist from the aircraft manufacturer was also present.

Visual inspection revealed no anomalies with the EPGS components that could be accessed, including circuit breaker settings and the condition of the wiring at the GCU 1 rack. Selectors on the EPGS control panel were found with their normal settings, including the AC ESS FEED push-button. However, the switch settings found were not considered to constitute reliable evidence of the settings in flight after the multiple busbar loss, given the possibility of subsequent disturbance. Similarly, the selected setting of the BRT/DIM toggle switch during the incident could not be reliably established.

Continuity and ground insulation checks of the electrical cables joining the No 1 IDG CTs and line CTs to GCU 1 showed no abnormalities.

1.12.4 Aircraft Checks

A GPU was connected to power the aircraft for a series of EPGS checks, but on this occasion the POWER AVAILABLE caption failed to illuminate. This was repeated with two other GPUs. As there appeared to be a problem with both GCU 1 and the GAPCU, both units were changed, after which the aircraft accepted ground power normally. With the system powered, TR 1 was found to be off-line, but energised normally after it had been reset via the MCDU. The CFDS indicated a hard fault with the No 1 Cabin Pressure Controller; this was not considered relevant to the incident.

In order to explore the EPGS behaviour, the aircraft was set up on the ground with the engines and APU running. Automatic transfer of power feed with assorted combinations of ground power, APU and IDG sources was normal. Checks of the AC ESS busbar manual transfer from AC BUS 1 to AC BUS 2 were carried out with various power source combinations.

Simulation of the incident event was carried out by first selecting GEN 1 to OFF, causing GLC 1 to open and AC BUS 1 to feed from another source. The Bus Tie push-button was then operated to open BTC 1, thus removing the supply to the AC BUS 1 and AC ESS busbars and illuminating the FAULT caption in the AC ESS FEED push-button switch. When the AC ESS feed switch was operated the power supply to the AC ESS busbar transferred over to AC BUS 2 and the ALTN caption in the push-button switch illuminated. The sequence was repeated successfully many times, both with the replacement GCU 1 and GAPCU and reportedly with the original units reinstalled; indications and system behaviour were normal in all cases.

With the AC ESS busbar de-energised, with either the original or the replacement GCU 1 and GAPCU installed, the following features were observed:

- Left pilot's PFD and ND and upper ECAM display blank
- All annunciator captions on EPGS control panel unlit, except:
    - ADIRS – ON BAT
    - AC ESS FEED button - FAULT
- Nos 1, 2 and 3 VHF radios inoperative
- Audio Control Panels No 1 and 2 unresponsive to selections
- Four pages of Inoperative Systems on ECAM display (Appendix 1 lists the expected system effects)

- Area lighting in the cabin illuminated
- Reading lights and 'No Smoke' captions in the cabin unlit on left side, lit on right side

Each time the AC ESS busbar was re-energised by selecting alternate feed, re-illumination of flight deck lighting, many annunciator captions and blank display units rapidly made it obvious that the system had reconfigured. The response was apparent around 0.75 seconds after operating the AC ESS FEED push-button switch.

1.12.5 Component Checks

1.12.5.1 General

Components of possible relevance to the event were removed and bench tested at manufacturers' facilities and, where relevant, strip-examined. Fault and troubleshooting data were retrieved from the GCU 1 and GAPCU NVMs. For reference, circuit components are identified by their FINs, in parenthesis.

No fault was found with the AC ESS FEED control and indicating circuit components, namely the circuit breaker (5XC), push-button switch (11XC), two relays (3XH and 12XE) and two contactors (3XC and 15XE).

1.12.5.2 Generator Control Unit No 1

GCU 1 (PN 767584J, SN 2959) was operated on an aircraft manufacturer's integration test rig intended to simulate the aircraft system. With GEN 1 selected off and the simulated EEPGS powered by ground power, an intermittent Phase B current was sensed by the No 1 IDG CT. The current fluctuated to 25-40A and on two occasions within a four-hour test period the GCU 1 registered a GLC 1 fault and executed the Welded GLC Protection function, thereby locking out BTC 1.

The GCU was then checked by its manufacturer, Hamilton Sundstrand, on a production test bench and the contents of its NVM downloaded. The manufacturer also subjected the unit to Environmental Stress Screening, where it was run on a test bench for several hours at temperatures ranging from -40°C to +70°C. One or two momentary IDG Phase B current signals were seen but, with this exception, no faults were found and no protection functions were triggered.

However, the unit was subsequently left permanently powered over an extended period and after around two weeks a DP trip occurred, associated with a Phase B current of 60A. Detailed examination of the CT sensing circuits identified an intermittent contact in a transformer that was part of the Phase B IDG CT circuit (the T5 transformer on the A2 wiring board). This could result in the Phase B IDG current intermittently being erroneously sensed as zero. However, the manufacturer considered that, because of electrical noise affecting the associated amplifier, the defect could also result in an erroneous sensed current of up to around 80A.

1.12.5.3 Ground and Auxiliary Power Control Unit

When checked on a production test bench, the GAPCU (PN 1700667D, SN 1742) failed the check. A fault message 'UUT RS485 communications failure' was given. Disassembly and physical examination revealed damage to three conductors in a flexible ribbon connector joining a GAPCU external connector socket (Socket B) to a socket on the A5 wiring board. The conductors were used to provide 3-phase external power signals to the GAPCU to enable it to monitor power quality; each was connected via a 3A circuit breaker.

Detailed examination revealed signs of electrical overstress damage to the ribbon, causing local severance and/or shorting of the three conductors. Metal spatter from the conductors and heat damage to the plastic laminate ribbon was evident in the damaged area. The evidence suggested that the overstress had been of short duration. The unit manufacturer considered that it could have been caused by a direct lightning strike to the external power socket pins or by a static discharge to the pins when a GPU was connected with the normal earth connection between the GPU and the aircraft absent. The damage would have prevented the GAPCU from accepting external power onto the aircraft.

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

See Section 1.12, page 38.

1.17 Organisational and management information

Not applicable.

1.18 Additional information

1.18.1 Aircraft certification standards

1.18.1.1 System failure analysis

The requirements for consideration of system failures and their effects at the aircraft design stage are defined in the standard EASA 25.1309 (formerly JAR-25.1309). Guidance is provided in document ACJ No 4 to the standard. This notes (Section 8.a.):

> *'The objective of JAR 25.1309 is to ensure an acceptable safety level for equipment and systems installed on the aeroplane. A logical and acceptable inverse relationship must exist between the Average Probability per Flight Hour and the severity of Failure Condition effects'.*

Failure condition classifications include the following, with relevant aspects of the defined effects summarised:

Minor	-	Slight reduction in functional capability or safety margins. Slight increase in crew workload.
Major	-	Significant reduction in functional capability or safety margins. Significant increase in crew workload. Possible injuries.
Hazardous	-	Large reduction in functional capability or safety margins, Excessive crew workload. Small number of serious or fatal injuries.
Catastrophic	-	Normally hull loss and multiple fatalities.

Allowable probability rates for the failure conditions are:

Failure Condition Classification	Minor	Major	Hazardous	Catastrophic
Probability per Flight Hour	$<10^{-3}$	$<10^{-5}$	$<10^{-7}$	$<10^{-9}$
Qualitative Probability	Probable	Remote	Extremely Remote	Extremely Improbable

In connection with compliance with JAR-25.1309 the ACJ (Section 9.b.(1)(iv)) notes that any analysis must consider:

> *'The effect of reasonably anticipated crew errors after the occurrence of a failure or Failure Condition.'*

It also notes (Section 12.a.) that:

> *'When assessing the ability of the flight crew to cope with a Failure Condition, the information provided to the crew and the complexity of the required action should be considered.'*

The ACJ (Section 9.c.) also notes that:

> *'systems and controls, including indicators and annunciations, must be designed to minimise crew errors which could create additional hazards.'*

The ACJ (Section 6.b.(2)(x)) also notes that the fail-safe design concept aimed at ensuring a safe design includes the principle of '*Margins or Factors of Safety to allow for any undefined or unforeseeable adverse conditions.*'

1.18.1.2 Manufacturer's failure analysis

According to the aircraft manufacturer, their theoretical failure analyses are predicated on the assumption that flight crews will always take the specific corrective actions in a timely manner. In-service experience shows that this may not always be achieved, as in this event.

For any reported in-service event such as this one, Airbus conduct a review in order to check the continued airworthiness of the fleet; this is to ensure that the initial design failure rates and assessments are still valid.

1.18.2 EPGS failure assessment

The loss of a single main generator channel was classified by airworthiness authorities as '*Minor*'; the associated calculated probability rate was 4.7×10^{-4}/flight hour. Loss of all main generation channels was categorised as '*Major*' (calculated failure probability rate of 5×10^{-7}/flight hour).

1.18.3 Generation control panel push-button switches

The selectors on the electrical power control panel consist of alternate-action push-button selector switches, whereby consecutive pushes cycle the switch between the different selections. Annunciator captions in each push-button illuminate to indicate the status or fault condition of the associated function.

A large number of similar switches are used on the flight deck for various functions. In the event of EPGS disruption, the power supplies for most of the switch captions could be lost. The aircraft design aimed to ensure that the captions in those switches likely to need operating in various failure situations would remain powered.

When a push-button is released its physical depression varies by only 1-2 mm between the ON and OFF selections.

1.18.4 G-EZAC Electrical Power Generation System history

Information from aircraft records indicated the following information relating to G-EZAC's EPGS in the period prior to the incident, shown in Table 1.

It appeared that the IDG 1 CT/GCU 1 fault registered during the engine ground run on the morning of the incident should have required a further GCU 1 replacement. However, after the GCU had been reset, the system behaviour was normal for the remainder of the ground run and the GCU remained installed.

The No 1 GCU (SN 2821) that had experienced problems on G-EZAC on the day before the incident and had been replaced was subsequently repaired by its manufacturer. This involved replacement of the two Static Random Access Memory (SRAM) devices on circuit board A3, following which the unit passed the tests required for release to service. These devices are used to memorise system parameters.

Information received suggested that, in comparison with similar aircraft, the level of EPGS problems indicated by the summary in Table 1 of G-EZAC's

Date	Event / Technical Log Entry	Fault / Maintenance Action
12-7-06	APU Generator will not come online	GAPCU reset
13-7-06	APU Generator inoperative	GAPCU reset
13-7-06	APU Generator will not come online.	GAPCU replaced 16-7-06
16-7-06	APU Generator inoperative.	GAPCU replaced. System works normally
17-7-06	AC experienced severe electrical interruptions. Re-settable then it became impossible	GAPCU replaced 22-7-06 (SN 1742 fitted)
13-9-06	Airbus Service Bulletin A320-24A1119-000-00 incorporated	External Power Socket replaced
13-9-06	6 Flights: 10.53 flight hours	
14-9-06	6 Flights: 10.23 flight hours	
14-9-06	GAPCU fault (3 flights before incident)	Considered to be Pin E (interlock circuit) problem
14-9-06	GCU 1 problems, twice. (GCU SN 2821). Technical Log entry: 'Gen 1 U/S'.	TSD: "Failsafe 01"
15-9-06	GCU1 replaced at Stansted (SN 2959 fitted).	Operational check and engine run carried out (specified in Aircraft Maintenance Manual)
15-9-06 0227 hrs	"FC 131 IDG1 CT/GCU1" fault during engine ground run.	GCU reset, system behaviour then normal, aircraft released to service
15-9-06 0539 hrs	Generator 1 tripped off-line (would not reset) during Stansted-Alicante flight. PFR fault identifier "IDG1 (E1-4000XU) GEN CT/ GCU1 (1XU1)"	Allowable Deferred Defect 1-46 raised. Fly in accordance with MEL 24-20-01, Expiry 26-9-06
15-9-06	"AC ESS bus 1 fail. Unable to reset iaw ECAM." PFR fault identifier "ELEC GEN 1 FAULT"	

Table 1

recent history was not exceptional. A number of the problems had apparently been caused by defective SRAM devices from a batch that was known to be potentially faulty. This was described in Airbus OIT 999.0106/06 issued on 24 August 2006, which listed the serial numbers of approximately 2,200 GCUs and GAPCUs affected. The issue had caused a substantial number of cases of GCU trips across the fleet. The information in the OIT had not been made available to flight crews.

The records showed that the GCU 1 (SN 2959) fitted to G-EZAC at the time of the incident had previously been installed in three different aircraft within a five month period. In each case, the unit remained in service for only a short time until it was removed because a fault had been indicated, as follows:

Date	Event	Finding	Outcome
Dec 2005	GCU SN 2959 manufacture		
March 2006	Fault Code 131	No fault found	Returned to service
April 2006	Removed due to trip	No fault found	SRAM replaced, returned to service
July 2006	Removed due to non re-settable trip	No fault found	Returned to service
September 2006	Fitted to G-EZAC as GCU 1		

1.18.5 GCU/GAPCU overhaul and repair

Normal practice was for a GCU or GAPCU rejected from service to be sent by the operator to an overhaul and repair facility and initially subjected to a standard acceptance test. The available information suggested that a substantial proportion of such units passed the test and were consequently released back to service 'No Fault Found' (NFF). As an example, for an unspecified period up to July 2006, 20 out of 69 GCUs (29%) removed for faults were reportedly returned to service NFF.

It was reportedly not routine practice for overhaul and repair facilities to record the fault codes recorded in the NVM of a unit sent for repair, or to retain a copy of the NVM contents. In some cases the NVM would be wiped before return to service and in others its contents would be left intact.

At the time of G-EZAC's incident, the unit manufacturer's overhaul and repair facility did not have a system to identify a unit that was repeatedly rejected from service, tested with NFF results and returned to service. There was also no system aimed at determining if a rejected unit might be suffering from a recurrent fault.

1.18.6 Other A320-series electrical system disturbance events

1.18.6.1 General

The AAIB is aware of other incidents of suspected EPGS disturbances. The events described below relate to aircraft equipped with Classic EPGS and EIS 1 CRT cockpit displays. As previously stated, G-EZAC was fitted with the EEPGS and EIS 2 LCD displays.

1.18.6.2 Airbus A319, Registration G-EUOB

The incident to G-EUOB (MSN 1529) occurred on 22 October 2005 and the AAIB investigation is reported in AAIB Report 2/2008. As the aircraft climbed to FL 200 on a revenue passenger flight in night VMC with autopilot and autothrust engaged, there was a major electrical system disruption. This resulted in the loss or degradation of a number of important aircraft systems. The crew reported that both the captain's and co-pilot's PFD and ND went blank, as did the upper ECAM display. The autopilot and autothrust systems disconnected, the VHF radios and the intercom were inoperative and most of the cockpit lighting went off. There were several other more minor concurrent losses.

The commander maintained control of the aircraft by reference to the outside visible night horizon and to the standby instruments, which he found difficult to see in the poor light. The lighting for the standby instruments had also been lost. With some standards of A320 the power supplies for the standby instruments themselves would have been lost. 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 ESS FEED switch to ALTN.

It was concluded that the captain's PFD and ND and the upper ECAM display had blanked because of loss of the left electrical network (AC BUS 1), for reasons that could not be determined, despite extensive investigation. The reason for the coincident blanking or severe degradation of the co-pilot's displays could not be determined.

The AAIB made the following Safety Recommendation, among others, as a result of the investigation:

> '**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.'

1.18.6.3 Airbus A321, Registration G-OZBE

G-OZBE (MSN 1707) suffered an EPGS disturbance incident on 23 April 2007. Aircraft systems suffered major disruption as the aircraft was climbing to cruising altitude after departure from Las Palmas Airport, Canary Islands. The captain's PFD and ND and one of the ECAM DUs blanked. The autopilot and autothrust disengaged and numerous caution, warning and crew action messages appeared. These did not make it apparent to the crew that there had been an EPGS failure.

Brief, intermittent reactivation of the blanked DUs hampered the crew in performing the ECAM actions. Both the co-pilot's displays subsequently twice blanked momentarily. After an initial selection, the crew was unable to tune radio navigation aids manually. The flight crew was also unable to communicate with the cabin crew, until disturbance to cabin electrical systems prompted a cabin crew member to visit the flight deck. Following initial contact, the flight crew experienced major difficulties in communicating with ATC. The APU failed to start when selected on.

The flight crew declared an emergency and turned back to Las Palmas, in VMC above a layer of low cloud. A number of substantial aircraft yaw disturbances occurred after one of the drill items had been actioned. The low cloud ceased just before the airport and the crew made a visual approach to land. The captain's PFD, ND and the upper ECAM DU became operational again shortly before landing. The aircraft landed safely, although above the specified maximum landing weight and with the nosewheel steering system inoperative. The ECAM Systems Display indicated a No 1 generator problem.

Examination and testing of the aircraft and of suspect EPGS components failed to reveal the fault responsible for the systems disruption, which could not be reproduced.

1.18.6.4 Airbus A320-Series aircraft, US-Registered

The incident occurred to a US-registered aircraft on 25 January 2008. Immediately after takeoff, in day VMC, the captain's PFD and ND and the lower ECAM DUs blanked and multiple systems were lost or degraded, due to a suspected EPGS failure, causing significant operational difficulties for the crew. The incident is under investigation by the National Transportation Safety Board (NTSB) of the USA.

1.18.7 Electrical System improvements

1.18.7.1 Automatic transfer of AC ESS busbar feed

AAIB Special Bulletin S9/2006 on G-EZAC's incident, published 13 December 2006, made the following Safety Recommendation:

> **Safety Recommendation 2006-143:** It is recommended that Airbus should introduce, for Airbus A320 series aircraft, a modification to automatically transfer the electrical feed to the AC Essential busbar in the event of the loss of the No 1 Main AC busbar.

On 31 May 2007, Airbus issued Service Bulletin A320-24-1120. Revision 01 was issued on 19 December 2007. The SB was optional and recommended modifications that would provide automatic reconfiguration of the power supply to the AC ESS and DC ESS busbars in the event of AC BUS 1 busbar loss. It categorised the modifications as 'Minor', denoting that they had no effect on airworthiness.

Airbus responded by letter on 17 July and 7 October 2008 to the recommendations made in AAIB Special Bulletin S9/2006. This stated, in relation to Safety Recommendation 2006-143, that the SB modification would be incorporated into the A320-series new-build standard in March 2007.

1.18.7.2 GCU logic

AAIB Special Bulletin S9/2006 on G-EZAC's incident, published 13 December 2006, made the following Safety Recommendation:

> **Safety Recommendation 2006-142:** It is recommended that Airbus should revise, for the A320 aircraft series, the fault monitoring logic of the Generator Control Unit to prevent the

monitoring system from incorrectly interpreting a fault within the GCU as an external system fault.

Following G-EZAC's incident, Hamilton Sundstrand proposed two possible changes to the GCU logic:

GCU CT disagree fault protection: This suggested change would provide the flight crew with a pre-flight alert to a discrepancy in the sensed IDG or Line CT current values. The proposal involved monitoring the difference between the IDG CT and Line CT current in each phase before the IDG came online. If the difference exceeded 20A for more than 160 ms the Generator Control Relay would be locked out, preventing the IDG from coming online and thus generating a GEN FAULT indication to the crew. An excessive current difference sensed while the IDG was online would continue to trigger the DP.

It appeared possible that the change could be included in a proposed upgrade to the GCU software, Standard 5.2, due to be released in the latter part of 2008 and to be recommended for retrofit at the next workshop visit of a GCU.

Welded GLC Protection improvement: A further proposed change involved monitoring the Line CT current, as well as the IDG CT current, and triggering the protection function only if both exceeded 25A in conditions when the GLC should be open.

Airbus stated in their response letters of 17 July and 7 October 2008 to the recommendations made in AAIB Special Bulletin S9/2006 that, in relation to Safety Recommendation 2006-142:

'The origin of this event is a lack of robustness in the differential protection trip implemented in the GCU EMM [[12]], which has caused the loss of AC ESS bus bar. Such failure mode cannot occur on GCU non-EMM. Affected aircraft are with GCU PN 767584x (where x could be A through J). To address this AAIB SR, AIRBUS has developed a new GCU std. The main objective of this new GCU standard is to improve the robustness of the differential protection trip related to the "GLC welded" failure mode. On top of that, this standard will be used to implement other corrections and improvements such as the management of the FIRE trip protection reset logic, the PW bypass valve failure

[12] Enhanced Manufacturing and Maintainability.

> *BITE message and other specific improvements for Long Range aircraft (this GCU is common between SA and LR fleet). The standard GCU EMM 5.2 will be available for all SA A/C models with GCU EMM, and will be standard in production for A320 family. Through a MSCN an AIRBUS SB will be issued to cover this modification.'*

Airbus stated that the three improvements have been incorporated into Modification 39670 which is available for retrofit via Service Bulletin A320-24-1124.

1.18.7.3 VHF radio system power supplies

AAIB Special Bulletin S9/2006 on G-EZAC's incident, published 13 December 2006, made the following Safety Recommendations:

> **Safety Recommendation 2006-144:** It is recommended that Airbus should advise all operators of A320 series aircraft with Radio Telephony (RTF) communications reliant upon a single busbar of the consequent possibility of loss of all RTF communications.
>
> **Safety Recommendation 2006-145:** It is recommended that, for A320 series aircraft with digital Audio Management Units, Airbus should take modification action aimed at ensuring that electrical power supplies required for Radio Telephony communications have an improved level of segregation.

Airbus stated in their response letters of 17 July and 7 October 2008 to the recommendations made in AAIB Special Bulletin S9/2006 that, in relation to Safety Recommendations 2006-144 and 2006-145:

> *'AIRBUS has developed modification 37782 that consists of an improvement of the AMU power supply logic in order to keep the digital AMU audio functions in case of DC essential bus loss, as already provided with an analogue AMU. This modification is standard for production aircraft from MSN 3153. Associated AIRBUS MSB A320-23-1333 has been issued on May 9, 2007 and is currently at revision 2 dated February 18, 2008.'*

Airbus also stated that: 'AIRBUS has issued FCOM TR 74 (issue 1 on March 2007, issue 2 on February 2008) to state on the loss of the VHF com in case of DC ESS BUS FAULT.'

1.19 New investigation techniques

No new techniques were used in this investigation.

2 Analysis

2.1 Operational aspects

2.1.1 Crew qualifications, experience and training

The two pilots were properly qualified and experienced in their respective roles to operate the flight. Both were adequately rested and had been on duty for 6 hours and 7 minutes when the incident started.

The pilots were not trained in how to respond to an electrical failure involving the unrecoverable loss of the AC BUS 1, AC ESS and other associated busbars, as this was not an anticipated failure mode. Nevertheless, they were able to manage the situation and continue safely to Bristol.

2.1.2 Aircraft dispatch for the incident flight

The aircraft was released for dispatch from Alicante in accordance with the approved procedures within the MEL. The engineer did not attempt to troubleshoot the No 1 generator fault; this is as expected given that the MEL did not require any such action to be performed prior to dispatch with the No 1 IDG inoperative.

Given the history of intermittent faults experienced on the A320-series EEPGS caused by GCU SRAM defects as described in the Airbus OIT issued in 2006, it is possible that maintenance personnel considered that the problem on the outbound flight was caused by an intermittent SRAM defect and was therefore not a significant issue.

2.1.3 Effects of the failure

The evidence shows that the loss of the AC BUS 1, AC ESS, DC ESS busbars and their dependant sub-busbars resulted in very widespread degradation or loss of multiple aircraft systems. This created an extremely demanding situation for the crew to manage. Following the failure, the commander, having lost his PFD and ND, handed over control to the co-pilot, whose displays were still available and who remained as PF. With the autopilot, flight director and autothrust unavailable, much of the co-pilot’s capacity would have been absorbed with the task of manually flying the aircraft.

A serious electrical system disruption on an aircraft that is heavily reliant on electronics for most aircraft systems, such as the A320-series aircraft, will inevitably have serious and widespread effects on many of the systems. The A320 EPGS design was considered acceptable because, in the event of loss of the AC ESS busbar, most of the affected systems would be restored by manually selecting the alternate feed, which Airbus considered would typically take around one minute. In-service experience has shown that on some occasions the changeover may take longer, or not be achieved at all, as in G-EZAC's case. In this case the aircraft was stable in the cruise in VMC conditions but the failure could equally have occurred in IMC conditions and at low level in a critical phase of flight, such as the approach to land. As TCAS operation was compromised, such a failure in congested airspace might also lead to an increased risk of collision with another aircraft. With the EGPWS also inoperative, there would be no warning of the risk of collision with terrain.

Other significant systems were affected, such as the cabin pressurisation system, where the automatic control function was no longer available. In this incident it did not cause the flight crew any difficulty, however had this failure occurred in other circumstances, the cabin altitude could increase excessively, requiring corrective action. The flight crew would then have to control the cabin pressure manually. Whilst the excessive cabin altitude warning would still operate, it would not be possible to deploy the passenger oxygen masks.

For these reasons, it was considered that the potential hazard of loss of the AC BUS 1, AC ESS and DC ESS busbars was more serious than the airworthiness authorities had assessed (loss of a single main generator channel was categorised as '*Minor*' - see Section 1.18.2, page 45).

A recommendation was made in AAIB Special Bulletin S9/2006, published on 13 December 2006, for Airbus to introduce a modification to automate the transfer of the electrical feed to the AC ESS busbar in the event of the loss of the AC BUS 1 busbar. The modification specified by the Airbus SB issued in 2007 provides such automatic reconfiguration for aircraft with either the Classic or Enhanced EPGS.

This modification is currently optional, but given the potentially serious safety implications of a delay or the inability to achieve manual AC Essential feed changeover, it is considered that the change should be mandated. The following Safety Recommendation is therefore made:

It is recommended that the EASA require modification of Airbus A320-series aircraft to provide automatic changeover of the electrical power feed to the AC Essential busbar in the event of de-energisation of the AC BUS 1 busbar. **(Safety Recommendation 2008-81)**

The EASA has responded formally to this Safety Recommendation, stating that they will mandate the installation of Airbus modification 37317 (SB A320-24-1120) by the issuance of an Airworthiness Directive.

2.1.4 AC Essential busbar loss indication

It was intended that the lost Essential busbars would be restored by the crew manually operating the AC ESS FEED push-button on the EPGS control panel in response to the ECAM message. The FAULT caption in the push-button that should have been illuminated in these circumstances should have aided the crew in locating the correct button.

No evidence was available from the aircraft examination to explain the reports by both pilots that the caption was not illuminated, even though the ECAM message was present. Both the power supply for the caption and the trigger for the ECAM message are routed through the same relay. Testing uncovered no anomalies with the relay, and the caption power supply source (AC BUS 2) remained energised throughout the incident. There was therefore no apparent technical reason for the caption failing to illuminate.

2.1.5 AC ESS FEED changeover selection

No evidence was found to explain the crew reports that operating the AC ESS FEED push-button selector had no effect. The system was subsequently found to operate normally and testing of the relevant components uncovered no defects in the system. However, it remained possible that a temporary anomaly, that was not repeated or uncovered, had prevented it from producing the expected effect.

Other possible explanations are that the wrong switch selection was made, or that the AC ESS FEED push-button was inadvertently pushed twice in rapid succession and thus accidentally set back to its original position before it had taken obvious effect. It has already been noted that the position of the button would provide no indication of the switch setting. However, no evidence was found to support either of these possibilities.

The reasons why the AC ESS electrical supply changeover did not occur with G-EZAC could not be established, but with a trained and experienced crew and relatively benign flight conditions, this was the case.

2.1.6 AC ESS FEED push-button selector

The flight crew of G-EZAC considered it significant that the selected position of the push-button selector could not be readily determined from the physical position of the button, as its position did not change significantly, whether selected or deselected. The determination of the switch selection therefore relied on their being able to discern whether or not the caption was lit. This push-button design potentially lacks one of the basic functions of a selector, that of always providing a reliable, immediate and unmistakable indication of its selection.

Push-button selectors of this type are used in the flight deck of A320-series and other aircraft. The system design aimed to ensure that power supplies for the captions in the selectors would remain powered in any foreseeable failure scenario.

While such a design logic may seem acceptable, it has significant practical limitations. The selected positions of all the flight deck selectors should be apparent when the aircraft is operating normally, but in some failure situations the crew would not be able to determine the settings of many flight deck selectors, as the power supplies for the caption lights may have been lost. The loss of this ability could prove critical in failure situations where the aircraft's systems are extensively affected and the pilots are unclear as to the cause of the problem and the appropriate corrective actions. The following Safety Recommendation is therefore made:

It is recommended that the EASA and the FAA introduce certification requirements aimed at ensuring that flight deck control selectors are designed such that an immediate and unmistakable indication of the selected position is always provided to the flight crew. (**Safety Recommendation 2008-83)**

2.1.7 Radio communication

The commander spent a significant amount of time trying to achieve radio contact with ATC, not realising that it would not be possible. This delayed his continuation of the ECAM actions. There was nothing in his previous training and no indications on the ECAM or elsewhere on the aircraft, including the documentation, that could have pointed to a complete loss of communication.

The commander was very concerned about the loss of communication and was anxious to avoid being intercepted by military aircraft because, given G-EZAC's degraded capability, he may not have been able to follow another aircraft. The risk of interception and possible offensive action was also a significant consideration in his decision to continue to Bristol. The prevailing aviation security climate has an impact on decisions made by flight crews and loss of radio communication thus assumes a greater degree of importance.

Two Safety Recommendations in relation to power supplies for the VHF radio systems were made in AAIB Special Bulletin S9/2006, published on 13 December 2006. In view of the potential hazard of a total communications loss given the current heightened aviation security environment, the following additional Safety Recommendations are therefore made:

It is recommended that the EASA requires the modification of affected Airbus A320-series aircraft so that the loss of a single busbar does not result in the complete loss of Radio Telephony communications. **(Safety Recommendation 2008-84)**

It is recommended that the EASA and the FAA re-categorise the loss of all Radio Telephony communications for public transport aircraft as 'Hazardous'. **(Safety Recommendation 2008-85)**

The time that the commander spent focussed on attempting to achieve radio communication delayed the completion of the remaining ECAM actions. As a result, it was 10 minutes before the transponder was switched to ATC 2 and the aircraft became visible again to Brest ATCC.

2.1.8 Potential for collision

The Brest ATCC radar screens did not display primary returns. Thus, when G-EZAC's ATC 1 transponder lost power and the secondary radar data was lost, the aircraft disappeared from the radar controller's screens. The simultaneous loss of radio contact meant that the controllers had no means of knowing where the aircraft was, or what had happened to it. This situation, which lasted for some 10 minutes, caused them considerable concern and presented a significant distraction at the critical time of shift changeover.

As G-EZAC was no longer visible on the Brest radar screens, the radar controller did not realise at first that there was a possible conflict with AAL63, also at FL 320. When he did recognise the possibility of a conflict, he had no information as to whether he should climb or descend AAL63. He decided on a descent and instructions were issued. However, there was then a discussion with AAL63 regarding the TCAS and the whereabouts of G-EZAC, which delayed AAL63's descent, increasing the potential risk of the two aircraft colliding.

The computations of the closest point of approach between the aircraft could not be exact but they indicated that, without intervention, they would have passed through the same airspace some 19 seconds apart. The absence of G-EZAC's ATC 1 transponder signal would have prevented AAL63's TCAS from detecting the conflict. As G-EZAC's TCAS was unpowered, no airborne collision avoidance protection was available. This is a further reason why an automatic changeover of the AC Essential busbar power supply is considered necessary.

2.2 Electrical Power Generation System

2.2.1 Electrical Power Generation System behaviour

2.2.1.1 Electrical power disruption

The evidence from crew reports, the PFR and the recorded data showed that the incident had resulted from de-energisation of AC BUS 1. The design configuration of the EPGS meant that the loss of AC BUS 1 inevitably caused immediate loss of the AC ESS and DC ESS busbars and the sub-busbars fed by them. DC BUS 1 probably also de-energised for a few seconds before then automatically recovering. The effects, in terms of the aircraft systems that were degraded or lost, were also consistent with the loss of AC BUS 1 and its dependant busbars and sub-busbars.

2.2.1.2 Cause of AC BUS 1 loss

The TSD obtained from GCU 1 during the investigation indicated that the loss of AC BUS 1 had resulted from IDG 1 tripping off-line because of operation of the Welded GLC Protection function. As well as de-exciting the IDG, this function locks out BTC 1, preventing it from closing, in order to protect the IDG from being back-fed with power from the feeder busbar. However, the BTC lockout also prevents AC BUS 1 and hence the ESS busbars, from automatically being fed from either IDG 2 or the APU generator.

2.2.1.3 No 1 Generator Control Unit defect

As GLC 1 was subsequently found to be fully serviceable, it was apparent that the Welded GLC trip by GCU 1 had been erroneous. Although standard acceptance testing passed GCU 1 as fully serviceable and fit for release back to service, durning more extensive testing it was occasionally possible to reproduce the fault briefly. Eventually a defective contact in a transformer within the GCU circuitry was identified, which could intermittently cause erroneous sensing of the IDG Phase B current. The current could apparently either be sensed as zero at times when there was actually a current flowing, resulting in a DP trip, or at other times as a positive current when the actual current was zero, potentially resulting in a Welded GLC trip.

Thus it was concluded that both the DP trip on the outbound flight and the Welded GLC Protection trip on the incident flight were probably attributable to the defective GCU 1 transformer.

2.2.2 Master Minimum Equipment List

G-EZAC's incident made it evident that, in the configuration in which the aircraft was dispatched for the incident flight, a single fault in an apparently minor component can result in severe disruption of the EPGS and of multiple aircraft systems.

Such a situation is undesirable given the level of disruption involved, which could present a significant hazard to the aircraft in certain circumstances. Although no reports of directly comparable previous cases were obtained during the investigation, a substantial number of reported cases of DU blanking have been reported. These were frequently associated with EPGS disruption and in many cases the root cause could not be determined. The following Safety Recommendation is therefore made:

It is recommended that the EASA require Airbus to review the A320-series Master Minimum Equipment List (MMEL) for the validity of dispatch with an IDG inoperative, given that an intermittent fault in a Generator Control Unit can result in significant disruption of aircraft systems. (**Safety Recommendation 2008-86**)

The Operational Procedure specified before dispatch with an IDG inoperative did not include a check for correct functioning of the AC ESS FEED changeover. As the EPGS is vulnerable to an erroneous Welded GLC Protection trip in this configuration, requiring a manual changeover of the AC ESS feed, it is considered that such a check would be beneficial. This would not only check the correct functioning of the changeover system, but also help to remind the crew of the location and function of the selector. The following Safety Recommendation is therefore made:

> It is recommended that the EASA require Airbus to revise the A320-series Master Minimum Equipment List to include a requirement to check for correct operation of the manual AC ESS FEED changeover function prior to dispatch with a main generator inoperative. (**Safety Recommendation 2008-87**)

The MEL Operational Procedure required a check of the APU fuel pump but did not provide a reference to the relevant procedure, which was elsewhere in the FCOM. As a result this check was not carried out. However, this did not have any bearing on subsequent events and is therefore not discussed any further.

2.2.3 Electrical Power Generation System Background

2.2.3.1 Aircraft maintenance background

Whilst G-EZAC had experienced an appreciable number of EPGS problems in the two months or so prior to the incident, maintenance staff reported that this was not exceptional. No further details could be obtained on the event reported on 17 July 2006: *'AC experienced severe electrical interruptions. Re-settable then it became impossible'*, but the difficulties were apparently resolved by changing the GAPCU. Many of the defect reports particularly concerned the GAPCU. It appeared likely that defective SRAM devices had caused a number of the problems, including the problem with the No 1 GCU that was replaced the day before the incident. Apart from the GCU 1 fault and possibly the GAPCU fault, there was no evidence to indicate that any other EPGS faults had been present at the time of the incident. At the time of writing, G-EZAC had not experienced any further significant EPGS anomalies since this incident.

The IDG 1 CT/GCU 1 fault registered during the engine ground run after GCU 1 had been replaced on the morning of the incident flight prompted a GCU 1 reset. The system behaviour was then normal for the remainder of the ground run. This fault should have required a further GCU 1 replacement, but it is likely that maintenance staff considered the fault to be spurious. Once this fault had been cleared and did not recur, there would have been no apparent justification for another GCU 1 replacement.

2.2.3.2 No 1 Generator Control Unit background

It was notable that the GCU 1 fitted to G-EZAC at the time of the incident had previously been rejected from service on three occasions within a recent five month period. Although no significant information on two of the events was available, it was possible that all three rejections had resulted from the same intermittent fault that resulted in this incident.

At the time of this incident, the GCU manufacturer's overhaul and repair facility did not have a system in place to trigger an alert for units that had been repeatedly declared unserviceable. Additionally, the production acceptance testing did not necessarily identify intermittent faults, such that units could be released back to service, only for the fault to recur. The unit could again be categorised as NFF and declared serviceable, to repeat the cycle once again. In an example period around 29% of rejected GCUs were returned to service as NFF.

It can be very difficult to find an intermittent fault by bench testing, as was the case for G-EZAC's GCU 1. However, it appeared that relatively simple measures, such as recording the fault codes stored in each unit sent for repair and tracking a unit's rejection history and previous faults might be effective in breaking the cycle. The following Safety Recommendations are therefore made:

It is recommended that Hamilton Sundstrand modifies its repair and overhaul procedures to ensure that a unit with an excessive service rejection rate or a recurrent fault is not repeatedly released back to service. (**Safety Recommendation 2008-88)**

It is recommended that the EASA and the FAA require that approved component repair organisations have procedures in place to identify units with an excessive service rejection rate or recurrent faults. **(Safety Recommendation 2008-89)**

2.2.3.3 GAPCU defect

Examination of the GAPCU after it had failed a bench test revealed severe electrical overheat damage to the three conductors used for external power monitoring. Static discharge resulting from connection of a GPU to the aircraft without the normal GPU/aircraft earth connection present, or lightning strike effects, appeared the most likely cause. The operator reported that the aircraft initially accepted ground power, after having shut down at Bristol following the incident. While this could not be positively confirmed, it suggested that the damage had probably occurred after the incident.

The damage would have prevented the GAPCU from accepting external power onto the aircraft, as occurred during the post-incident ground testing. However, the defect did not appear to affect any other GAPCU functions and had no effect during the testing of the transfer of the AC ESS busbar feed from AC BUS 1 to AC BUS 2. No connection between the GAPCU damage and the GCU 1 defect could be found, and no effect on the functioning of the EPGS, with the exception of ground power acceptance, seemed possible.

2.2.4 Electrical Power Generation System improvement

2.2.4.1 Monitoring improvements

As previously noted, a Welded GLC Protection trip can have serious effects on the EPGS, and AAIB Special Bulletin S9/2006 recommended improvements aimed at preventing erroneous operation of the function. The EPGS supplier proposed two related changes to GCU logic, namely the addition of GCU CT Disagree Fault Protection alerting and the addition of Line CT current monitoring to the Welded GLC Protection detection function. It appeared possible, subject to detailed consideration by specialists, that these measures could significantly improve the GCU fault monitoring logic.

Following a Safety Recommendation for Airbus to revise the GCU fault monitoring logic, made in AAIB Special Bulletin S9/2006, published on 13 December 2006, Airbus has stated that an updated GCU software standard has been developed. In view of the defective GCU logic revealed by the investigation into G-EZAC's incident, the following additional Safety Recommendation is made:

> It is recommended that the EASA require improvements to the fault monitoring logic of the type of Generator Control Unit (GCU) used on A320-series aircraft with the aim of preventing the monitoring system from incorrectly interpreting a fault within the GCU as an external system fault. (**Safety Recommendation 2008-90**)

2.3 Airworthiness Considerations

2.3.1 Failure Modes and Effects Analysis

The de-energisation of AC BUS 1 causes extensive effects on the electrical power system and consequently on multiple aircraft systems. The aircraft manufacturer's theoretical failure analyses assumed that flight crews would always achieve AC Essential Feed changeover in a timely manner. However, if this is not achieved, the aircraft continues to operate in a significantly degraded condition, one that appears not to have been fully considered during aircraft certification.

This incident shows that this assumption does not always hold true and therefore suggests that such analyses should consider the effects of a delayed or non-achieved flight crew action.

The current aircraft certification requirements specify that any failure analysis must consider *'the effect of reasonably anticipated crew errors after the occurrence of a failure…'*, but do not require consideration of a delayed crew action or the inability to complete the required crew action.

Therefore the following Safety Recommendation is made:

> It is recommended that the EASA extend the guidance material provided for the EASA 25-1309 certification standard for failure effect analyses, to include consideration of the effects of delayed or non-achieved crew actions, in addition to crew errors. **(Safety Recommendation 2009-063)**

2.4 Flight recorders

2.4.1 Recorder technology

2.4.1.1 CVR power supply

Analysis of the MEL procedure performed prior to dispatch from Alicante clearly identified both the flight crew actions and the audible operation of the electrical contactors. Loss of the CVR recording after the loss of the DC ESS SHED busbar led to a significant loss of evidence that might have assisted this investigation. Also, with the loss of radio communications, interpretation of the flight crew actions was based purely on the crew's recollections, without the benefit of ATC voice recordings.

This incident highlighted yet another case where the installation of RIPS would have benefited the investigation. G-EZAC was not required to be fitted with a RIPS as it was certified prior to development of ED112. As a technical and operating standard currently exist, and steps are in place to implement RIPS, albeit over a significant time period, a Safety Recommendation from the AAIB was not considered necessary.

2.4.1.2 Cockpit image recording

Additional recorded information that would have assisted this investigation included:

- fault light indications on the overhead panel
- ECAM messages and how these messages were then actioned by the flight crew
- evidence of any electrical power switching and APU GEN operation

During this and a number of previous investigations, the AAIB has been unable to reconcile crew recollections of cockpit indications and switch positions with those recorded by the FDR. The FDR does not record all the information displayed to the flight crew on the cockpit displays, nor does it record all switch positions.

An effective solution would be difficult to implement with the current recording technology and the cost is likely to be prohibitive. An alternative solution is the provision of cockpit image recording. Recorded images, coupled with the FDR data, would allow accident investigators to better understand what was being displayed to the flight crew, what crew actions were taken and their resultant effects on the aircraft systems.

Although the benefits of cockpit image recording have been accepted by accident investigators, the likely political and privacy issues will make the implementation of such a system challenging. As yet RIPS has not been considered for cockpit image recording systems.

3 Conclusions

3.1 Findings

1. The flight crew involved in the incident were licensed and qualified to operate the flight and were in compliance with the applicable flight time and duty time limitations.

2. The aircraft held a valid Certificate of Airworthiness and was maintained in accordance with an EASA-approved maintenance programme.

3. A reset of the No 1 generator control unit during maintenance carried out prior to despatch of the aircraft from London Stansted was technically incorrect but in accordance with common general practice.

4. The No 1 engine-driven generator tripped off-line on the flight sector between Stansted and Alicante and would not reset.

5. The aircraft was despatched from Alicante on the incident flight with the APU generator substituting for the No 1 generator, in accordance with the operator's MEL, which reflected the manufacturer's MMEL.

6. The MMEL did not require the reason for the No 1 generator trip to be investigated prior to dispatch.

7. The Operational Procedure in the MMEL did not contain the associated procedure for a check of the APU fuel pump.

8. While in the cruise at FL 320 in VMC, the aircraft suffered severe disruption of the electrical power system, causing multiple aircraft systems either to cease operating or to become degraded, significantly increasing the flight crew's workload.

9. All means of radio communications became inoperative and remained so because they all relied on a single busbar which de-energised and was unavailable for the remainder of the flight.

10. The loss of all means of radio communications caused the crew considerable concern and delayed their continuation of the ECAM actions.

11. G-EZAC's transponder signal was lost for about 10 minutes, during which time the aircraft was not visible to Brest ATCC radar, leading to reduced separation with another aircraft.

12. The loss of power supply to the ATC 1 transponder rendered the TCAS inoperative until the ATC 2 transponder was selected some 10 minutes later.

13. Despite the pilots' attempts to follow the ECAM action messages, many of the affected aircraft systems were not recovered.

14. The flight crew reported that no captions were visible in the AC ESS FEED push-button selector switch and that operation of the switch failed to reconfigure the power supply with the result that power to the left electrical network could not be restored in flight. During subsequent testing on the ground, the system was found to operate normally.

15. The flight crew could not determine the settings of certain flight deck push-button selectors as the button position did not change significantly with selection and the caption lights were not visible.

16. The CVR ceased to operate following the loss of the AC ESS SHED busbar.

17. The FDR did not record any switching of the AC BUS 2-to-AC ESS contactor throughout the flight.

18. The potential effect of loss of all three VHF radios was categorised by the airworthiness authorities as 'Major' but, in the current security climate, was judged to be more severe.

19. An intermittent fault was found in an electronic component of the No 1 generator control unit (GCU 1) which probably caused the No 1 generator trip on the outbound flight.

20. Recurrence of the GCU 1 fault during the incident flight probably caused the de-energisation of AC BUS 1 and the consequent severe electrical system disruption.

21. The GCU 1 had repeatedly been rejected from service prior to the incident, possibly because of recurrence of the same intermittent fault, and returned to service without the fault having been found, but still present.

22. No effective system aimed at identifying units repeatedly rejected from service and not found to be faulty, or units suffering repetitive faults, was in place at the GCU manufacturer's repair organisation.

3.2 Causal factors

The investigation identified the following causal factors in this incident:

1. An intermittent fault in the No 1 Generator Control Unit, which caused the loss of the left electrical network

2. An aircraft electrical system design which required manual reconfiguration of the electrical feed to the AC Essential busbar in the event of de-energisation of the No 1 AC busbar, leading to the loss or degradation of multiple aircraft systems, until the electrical system is reconfigured

3. The inability of the flight crew to reconfigure the electrical system, for reasons which could not be established

4. Master Minimum Equipment List provisions which allowed dispatch with a main generator inoperative without consideration of any previous history of electrical system faults on the aircraft

5. Inadequate measures for identifying Generator Control Units repeatedly rejected from service due to repetition of the same intermittent fault

4 Safety Recommendations

Four Safety Recommendations were made in AAIB Special Bulletin S9/2006, published 13 December 2006, as follows:

4.1 **Safety Recommendation 2006-142:** It is recommended that Airbus should revise, for the A320 aircraft series, the fault monitoring logic of the Generator Control Unit to prevent the monitoring system from incorrectly interpreting a fault within the GCU as an external system fault.

4.2 **Safety Recommendation 2006-143:** It is recommended that Airbus should introduce, for Airbus A320-series aircraft, a modification to automatically transfer the electrical feed to the AC Essential busbar in the event of the loss of the No 1 Main AC busbar.

4.3 **Safety Recommendation 2006-144:** It is recommended that Airbus should advise all operators of A320 series aircraft with Radio Telephony (RTF) communications reliant upon a single busbar of the consequent possibility of loss of all RTF communications.

4.4 **Safety Recommendation 2006-145:** It is recommended that, for A320 series aircraft with digital Audio Management Units, Airbus should take modification action aimed at ensuring that electrical power supplies required for Radio Telephony communications have an improved level of segregation.

This report makes 10 further Safety Recommendations:

4.5 **Safety Recommendation 2008-81:** It is recommended that the EASA require modification of Airbus A320-series aircraft to provide automatic changeover of the electrical power feed to the AC Essential busbar in the event of de-energisation of the AC BUS 1 busbar.

4.6 **Safety Recommendation 2008-83:** It is recommended that the EASA and the FAA introduce certification requirements aimed at ensuring that flight deck control selectors are designed such that an immediate and unmistakable indication of the selected position is always provided to the flight crew.

4.7 **Safety Recommendation 2008-84:** It is recommended that the EASA requires the modification of affected Airbus A320-series aircraft so that the loss of a single busbar does not result in the complete loss of Radio Telephony communications.

4.8 **Safety Recommendation 2008-85:** It is recommended that the EASA and the FAA re-categorise the loss of all Radio Telephony communications for public transport aircraft as 'Hazardous'.

4.9 **Safety Recommendation 2008-86:** It is recommended that the EASA require Airbus to review the A320-series Master Minimum Equipment List (MMEL) for the validity of dispatch with an IDG inoperative, given that an intermittent fault in a Generator Control Unit can result in significant disruption of aircraft systems.

4.10 **Safety Recommendation 2008-87:** It is recommended that the EASA require Airbus to revise the A320-series Master Minimum Equipment List to include a requirement to check for correct operation of the manual AC ESS FEED changeover function prior to dispatch with a main generator inoperative.

4.11 **Safety Recommendation 2008-88:** It is recommended that Hamilton Sundstrand modifies its repair and overhaul procedures to ensure that a unit with an excessive service rejection rate or a recurrent fault is not repeatedly released back to service.

4.12 **Safety Recommendation 2008-89:** It is recommended that the EASA and the FAA require that approved component repair organisations have procedures in place to identify units with an excessive service rejection rate or recurrent faults.

4.13 **Safety Recommendation 2008-90:** It is recommended that the EASA require improvements to the fault monitoring logic of the type of Generator Control Unit (GCU) used on A320-series aircraft with the aim of preventing the monitoring system from incorrectly interpreting a fault within the GCU as an external system fault.

4.14 **Safety Recommendation 2009-063:** It is recommended that the EASA extend the guidance material provided for the EASA 25-1309 certification standard for failure effect analyses, to include consideration of the effects of delayed or non-achieved crew actions, in addition to crew errors.

R G Ross
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Air Accidents Investigation Branch
Department for Transport
July 2009

Appendix 1

Effects on Aircraft Systems of Loss of AC BUS 1, AC ESS and DC ESS busbars

Information from the A319 Flight Crew Operating Manual (FCOM) indicated that de-energisation of AC BUS 1, AC ESS, AC ESS SHED, DC ESS and DC ESS SHED busbars would disable or degrade the following components or systems (other systems may also be indirectly affected):

AC BUS 1

1. Blue hydraulic pump
2. Blue hydraulic system
3. Spoiler 3 on both wings
4. Air Data Reference System (ADR) 3
5. Radio Altimeter (RA)1
6. Captain TAT
7. Left windshield heater
8. Left window heater
9. Thrust Reverser 1
10. Left & Right Fuel tank pump 1
11. Centre tank pump 1
12. Vent blower
13. Galley fan
14. Cargo vent
15. Nosewheel steering
16. Main galley
17. Braking and Steering System (BSCU) 1
18. Display Management Computer (DMC) 3
19. Ground Proximity Warning System (GPWS)
20. CAT 3 landing capability
21. Lavatory smoke detector
22. Left cabin fan
23. Radar 1
24. Standby pitot / AOA sensors
25. Air Traffic Service Unit (ATSU)
26. Engine 1 Ignition system B
27. Engine Vibration Monitoring Unit (EVMU) for both engines
28. Cockpit printer
29. Air conditioning controller lane A
30. Hydraulic quantity indication
31. Traffic alert and Collision Avoidance System (TCAS)
32. Slat operation will be slower than normal
33. HF 1

Appendix 1

AC ESS and AC ESS SHED

1. Air Data Reference System (ADR) 1
2. Instrument Landing System (ILS) 1
3. GPS 1
4. Rudder trim system 1
5. Rudder travel limiter system 1
6. CAT 2 landing capability
7. System Data Acquisition Concentrator (SDAC) 1
8. Captain's pitot
9. Captain's Angle of Attack (AOA)
10. Ground Proximity Warning System (GPWS)
11. Yaw damper 1
12. Flight Warning Computer (FWC) 1
13. Display Management Computer (DMC) 1
14. Engine 1 and 2 ignition system A
15. Radio Management Panel Lighting
16. VOR 1
17. MCDU 1
18. Captain's Primary Flight Display (PFD)
19. Captain's Navigation Display (ND)
20. Cockpit Voice Recorder (CVR)
21. ECAM Upper display
22. ATC 1
23. DME 1
24. HF 1
25. Digital Distance and Radio Magnetic Detector (DDRMI)
26. APU fuel pump
27. Passenger oxygen masks (auto and manual deployment)
28. ADF 1
29. CAT 1 landing only

DC ESS

1. Engine Master Levers (EML)
2. Blue Hydraulic system
3. Spoiler 3, both wings
4. VHF 1
5. Audio Control Panels (ACP) 1 and 2
6. Wing anti-ice
7. Autopilot 1

Appendix 1

8. Autothrust
9. Fuel Control Unit (FCU) 1
10. Flight Augmentation Computer (FAC) 1
11. Left fuel tank pump 1
12. Right fuel tank pump 1
13. Thrust Reverser 2
14. Engine 2 start
15. Cabin pressure system 1
16. Vent extract
17. Blue electric pump
18. Ground Proximity Warning System (GPWS)
19. Engine 1 loop A
20. Engine 2 loop B
21. Flight Control Data Concentrator (FCDC) 1
22. CAT 3 landing capability
23. Cockpit brake pressure indicator
24. Flight interphone
25. Engine Interface Unit (EUI) 2 – autothrust, engine start and thrust reverser
26. Avionics air conditioning valve
27. Standby compass light
28. HP fuel shutoff valves
29. Slats and Flaps Control Computer (SFCC) 1
30. Radio Management Panel (RMP) 1
31. Hydraulic fire valves for both engines
32. Ram air inlet
33. ECAM control panel
34. Left loudspeaker
35. ECAM status will display CAT 3 SINGLE whereas actual landing capability is CAT 2

DC ESS SHED

1. Cabin oxygen mask automatic drop
2. Cross-bleed valve manual control
3. Cabin Intercommunication Interface System (CIDS) 1 smoke detection
4. Standby ALTI vib
5. Crew oxygen valve
6. Flight Management and Guidance Computer (FMGC) 1
7. Bleed Monitoring Computer (BMC) 1
8. Fuel Quantity (FQ) 1 channel 1

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2/2008	Airbus A319-131, G-EUOB during the climb after departure from London Heathrow Airport on 22 October 2005.	January 2008
3/2008	British Aerospace Jetstream 3202, G-BUVC at Wick Aerodrome, Caithness, Scotland on 3 October 2006.	February 2008
4/2008	Airbus A320-214, G-BXKD at Runway 09, Bristol Airport on 15 November 2006.	February 2008
5/2008	Boeing 737-300, OO-TND at Nottingham East Midlands Airport on 15 June 2006.	April 2008
6/2008	Hawker Siddeley HS 748 Series 2A, G-BVOV at Guernsey Airport, Channel Islands on 8 March 2006.	August 2008
7/2008	Aerospatiale SA365N, G-BLUN near the North Morecambe gas platform, Morecambe Bay on 27 December 2006.	October 2008
1/2009	Boeing 737-81Q, G-XLAC Avions de Transport Regional ATR-72-202, G-BWDA, and Embraer EMB-145EU, G-EMBO at Runway 27, Bristol International Airport on 29 December 2006 and 3 January 2007.	January 2009
2/2009	Boeing 777-222, N786UA at London Heathrow Airport on 26 February 2007.	April 2009
3/2009	Boeing 737-3Q8, G-THOF on approach to Runway 26, Bournemouth Airport, Hampshire on 23 September 2007.	May 2009