SERIOUS INCIDENT

Aircraft Type and Registration:	Boeing 737-36Q, G-GDFT
No & Type of Engines:	2 CFM56-3C1 turbofan engines
Year of Manufacture:	1998
Date & Time (UTC):	3 September 2014 at 1958 hrs
Location:	East Midlands Airport
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 5 Passengers - 152
Injuries:	Crew - None Passengers - 1 (Minor)
Nature of Damage:	R1 relay damage
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	59 years
Commander's Flying Experience:	10,600 hours (of which 4,100 were on type) Last 90 days - 294 hours Last 28 days - 54 hours
Information Source:	AAIB Field Investigation

Synopsis

The aircraft landed at East Midlands Airport following an electrical failure in flight, which the crew diagnosed as a failure of the battery busbar[1]. As the aircraft taxied towards its parking stand, an acrid smoke haze appeared within the cabin and flight deck and an emergency evacuation was carried out. Although the aircraft was successfully evacuated, cabin communication difficulties were encountered due to the failure of the PA system and a fault with a loud hailer unit.

The battery bus failure was caused by one or more loose R1 relay terminals, leading to a break in electrical continuity. The acrid smoke in the cabin and cockpit was a direct result of the relay failure. The loss of the air cycle machine (ACM) cooling fans caused dust and oil residue to burn off the hot metal duct surfaces in the air conditioning system and the resulting fumes entered the cabin, prompting the evacuation.

History of the flight

The electrical system malfunction

G-GDFT was operating a Commercial Air Transport (CAT) flight from Ibiza Airport, Spain, to East Midlands Airport, UK with 152 passengers and five crew members on board. At

Footnote

[1] Busbar: an electrical conductor distributing power from a power source, such as a battery, to electrical components.

1908 hrs, the aircraft was routing towards reporting point AVANT[2] and descending when the commander, who was making his arrival PA to the passengers, became aware that the PA system had failed. The flight crew then noticed indications of other, seemingly unconnected, failures which included faults with: the left equipment cooling fan; a radio; the weather radar; the autobrake; and the power supply to the standby attitude indicator and standby compass. In addition, indications of terrain, reference speeds, engine fuel flow and N1 (low speed compressor) rpm disappeared from the pilots' displays.

The crew discussed the situation, diagnosed that the aircraft had a problem with the battery busbar, but commented that there were no Non-normal Checklists (NNC) in the Quick Reaction Handbook (QRH) to help them. They also noted that the battery on its own was capable of providing power to systems for approximately 30 minutes. The commander told ATC that the aircraft had suffered a partial electrical failure and asked for expeditious routing to East Midlands Airport.

The cabin interphone was not working and so the co-pilot opened the flight deck door to attract the attention of the Senior Cabin Crew Member (SCCM). The SCCM entered the flight deck and the commander briefed her on the situation and his intention to make an approach and normal landing at East Midlands Airport.

When the SCCM returned to the cabin, she briefed the other cabin crew members on the situation and told the crew member at the rear of the aircraft to follow her (the SCCM) lead if circumstances arose where the crew member did not know what was happening. When the SCCM tried to use the PA to brief the passengers, she found that it did not work. She tried using the loud hailer but it became apparent that her instructions were not being heard more than two or three rows ahead of her. She tried to increase the output volume, but the volume control had broken, so she walked through the cabin briefing the passengers a few rows at a time.

After further discussion, the flight crew decided that the aircraft had a problem with the standby power supply. The commander, unsure whether or not the battery was being discharged by aircraft systems, and unsure whether or not electrical power to those systems would be lost at some point, asked the co-pilot to declare a PAN. ATC vectored the aircraft to intercept the localiser for an ILS approach to Runway 09 at East Midlands Airport. Before commencing the approach, the crew reminded themselves that the autobrakes were inoperative and manual braking would be required on the runway, and that the speedbrakes would have to be deployed manually on touchdown. The surface wind at the airport was from 070° at 7 kt, there were few clouds at 3,000 ft, broken clouds at 4,800 ft, and the QNH was 1022 hPa.

During the approach, when the co-pilot selected the landing gear to DOWN, there were no indications in the flight deck to show whether or not the gear had extended fully and locked in place. The crew decided to discontinue the approach to establish whether the landing gear had lowered correctly. They continued towards the airport and flew above the runway at 1,000 ft amsl while ATC personnel tried to establish visually whether the landing gear had

Footnote

2 AVANT is located at N5049.2 W00056.3.

extended. ATC subsequently reported to the crew that the nose gear appeared to be down, but it was too dark for them to see the state of the main landing gear. The aircraft climbed to 3,000 ft and re-positioned for a further approach, during which time the co-pilot used observation ports in the floor of the main cabin and of the flight deck to establish visually that the landing gear had extended properly. The aircraft landed without further incident at 1954 hrs and began to taxi towards its stand.

The evacuation

As the aircraft approached its stand, the cabin crew members sitting near the forward exits smelt smoke and the SCCM decided to tell the flight crew. She entered the normal entry code to request access to the flight deck and began knocking on the flight deck door. She could see smoke in the cabin which appeared to be coming from near the over-wing exits and which looked "misty from seat level up". She also noticed that some passengers were standing up. Because the flight crew had not opened the door, she entered the emergency entry code into the door locking system and then continued to knock on the door.

The pilots also smelt a strong acrid smell which they "felt in the throat". They heard the SCCM knocking on the door and could hear voices and noises from the cabin. The commander instructed the co-pilot to give the "CABIN CREW AT STATIONS" command, which would ready them for a possible evacuation, but the PA system was not working. The co-pilot opened the flight deck door to speak to the SCCM and, as the door opened, the pilots thought that the smell became worse. The SCCM entered the flight deck and reported that they needed to evacuate, the fire alarms had activated and there was smoke in the cabin.

The commander declared a MAYDAY, telling ATC that there was acrid smoke in the cabin and that he needed to evacuate the aircraft. He instructed the co-pilot to begin the evacuation and both pilots carried out their respective actions from the evacuation checklist.

The SCCM, at the forward left exit (1L), deployed the emergency slide and supervised passengers leaving the aircraft through that exit. The cabin crew member at the 1R exit deployed the 1R slide but it twisted as it inflated and became unusable. She guarded the doorway to prevent passengers leaving through the 1R exit and was later helped in that task by the pilots. The cabin crew member at the aft left exit (L2) was unaware initially that the aircraft was to be evacuated and she disarmed the door in preparation for a normal disembarkation. When she saw through the window that passengers were sliding off the trailing edge of the left wing, she re-armed the door, deployed the slide and shouted for passengers to come towards her to use her exit.

The Airport Fire and Rescue Service (AFRS) had been alerted at approximately 1926 hrs that the aircraft had an electrical problem and had positioned three rescue vehicles at the front of the fire station. After the aircraft landed, the vehicles followed it as it taxied towards its stand and were therefore on scene immediately after the commander declared his intention to evacuate. Members of the AFRS assisted passengers during the evacuation and, afterwards, entered the cabin to search for signs of heat or smoke. Although they reported that there was a smoke layer throughout the cabin, no signs of a heat source were detected in the cabin, avionics bays or cargo holds by their thermal imaging camera.

Information from the flight crew

The pilots were not sure whether the battery was discharging and did not know which additional systems would be lost if it discharged fully. Despite the fact that both engine driven electrical generators were functioning normally, the pilots decided that it would be sensible to attempt to land within 30 minutes from when the symptoms were first observed. This was because they expected a fully charged battery to be able to power connected systems for at least 30 minutes. Despite uncertainty over the exact nature of the failure, the pilots were content that they knew which systems would be unavailable during the landing.

Recorded data

The aircraft was fitted with a CVR and an FDR. Both recordings captured the onset of the problem and stopped when electrical power was disconnected as part of the evacuation checklist. The recordings of the ATC communications were also analysed. Pertinent extracts are provided in the History of the flight section of this report.

The data showed that the crew action of switching the standby power to battery during the evacuation checklist resolved many of the FDR parameter losses triggered by the original failure.

Aircraft description

General

The Boeing 737 is an all-metal, low-wing passenger aircraft powered by two CFM56-3C1 turbofan engines. Primary electrical power is supplied by two engine-driven generators which each supply three-phase 115V AC 400Hz. Each generator normally supplies its own bus system but it can also supply power to the transfer bus of the opposite side automatically via the Bus Transfer Relay if one generator fails. The APU drives a generator that can supply power to one Main AC Bus and both Transfer Buses in flight. The DC system consists of three major buses: DC Bus 1, DC Bus 2, and the Battery Bus. DC Bus 1 and DC Bus 2 are powered directly by two Transformer Rectifier (TR) units that operate in parallel, each receiving AC inputs power from its respective 115V AC Transfer Bus. These two buses are backed up by a third, identical TR (TR-3) through an isolation diode. In addition to its back-up function, TR-3 is the primary source of power for the Battery Bus. As long as power is available to TR-3, it will power the Battery Bus. If power is lost to TR-3, the Battery Bus will automatically transfer to receive power from the Hot Battery Bus.

The aircraft is air-conditioned and pressurised using ambient external air and hot air generated from the engine compressors. The system operates automatically to maintain the settings and demands required of it using electro-mechanical devices.

Battery busbar description

The third TR or the Hot Battery Bus supplies 28V DC to the Battery Bus through a series of relays: Battery Bus Relay (R355), Battery Bus Relay Auto (R1), and Battery Bus Relay Manual (R326). If both Main AC Buses lose power, the Hot Battery Bus automatically connects to the Battery Bus via Battery Bus Relay Auto (R1), providing power to the

115V AC (via the Static Inverter) and 28V DC Standby Systems. If the Battery Bus Relay Auto (R1) fails in an open circuit condition, power may be restored to the Battery Bus by selecting the Standby Power Switch to the BAT position. This action connects the Hot Battery Bus to the Battery Bus via Battery Bus Relay Manual (R326).

Pressurisation control

The pressurisation system is electrically operated and electronically controlled and meters the exhaust of ventilation air to provide controlled pressurisation to the passenger cabin and cockpit. The main components in the system are: a pressure controller, cabin and cargo compartment pressurisation outflow valves, pressure sensing devices, and an indication system.

The outflow valves are electrically driven and are fitted at the front and rear of the aircraft. The rear valve controls the cabin pressure whilst the forward valve, working in harmony with the rear outflow valve, controls the cargo and avionics bay pressurisation. In normal operation the rear outflow valve receives signals from the pressure controller to modify the position of its gate valve automatically to maintain differential cabin pressure. At touchdown the landing gear air/ground sensor signals the controller, which modifies the outflow valve opening to match cabin pressure with ambient pressure on the ground.

Air conditioning

Air conditioning and cabin ventilation is provided by two cooling packs which receive high energy and hot air bled from the engine compressors. The cooling packs consist of heat exchangers, water extractors, control devices and an air cycle machine (ACM). The ACM is an energy change machine which uses an air-driven compressor and turbine to extract heat energy from the bleed air. This device operates automatically, is self-lubricating and runs at very high speed. The cooling pack machinery heat exchangers are cooled using ambient ram air assisted by electrically driven fans.

Engineering investigation

Electrical system

Following the incident, the ground engineers made the aircraft safe and disconnected the battery. During these actions they were aware of an “odd hot” smell, but could not pinpoint the source. With the emergency services present, access was gained to the equipment bays in order to locate and isolate potentially damaged equipment, but all appeared normal. When the AAIB attended the aircraft the same night, nothing unusual was detected. On the morning after the incident, the aircraft was moved to a hangar at East Midlands to troubleshoot the problem. There was no obvious evidence of equipment failure so, after having taken appropriate safety precautions, the battery was reconnected and AC ground power applied to the aircraft. As systems were progressively brought on-line, exactly the same losses and indications experienced by the crew during the incident reappeared. However, at no point during this testing did the aircraft produce smoke or a smell of burning.

An examination of the circuit diagrams and the list of system losses indicated that the fault lay with the R1 or R326 relay. Power-off continuity checks were carried out across the two pairs of terminals on the R1 relay, but these were inconsistent and therefore inconclusive. The R1 relay was removed to aid further examination, but its removal was somewhat difficult as the terminals were loose and tending to rotate rather than remain stationary when an undoing torque was applied to the nuts. The outer collars had to be gripped with pliers in order to remove the nuts. It was difficult to carry out this task in the confined area at the bottom of the P6 bay in which the relay is located. It was also observed that the relatively large and stiff ‘A’ gauge cables and terminations were rigid, tightly tied within their wiring harness and did not naturally align with the terminals when the nuts were removed. When examined, the relay appeared to contain a loose object which rattled within the casing. Closer inspection of the relay terminals B1 and B2 found them to be loose and no longer fixed to their insulated mounting in the relay, to the extent that they fell out when the relay was inverted. The A1 and A2 terminals were also loose within their insulated collar, but remained in place. Figure 1 shows the R1 relay after removal.

Figure 1

R1 relay with detached B1 and B2 terminals

A replacement relay was fitted and further aircraft power supply tests were carried out, during which all aircraft systems functioned normally. In order to verify the diagnosis, the aircraft ground power was left on the aircraft for approximately one hour, with no emergent faults. The R326 relay was found not to be involved and operated correctly.

Heat and smoke

Further system and equipment inspection found the ACM lubrication oil levels to be low and the reservoir sight glasses slightly discoloured from overheating due to the loss of the cooling fans following the electrical failure. The ACMs were therefore replaced as a precaution. There was no evidence of heat distress or fire within any of the other aircraft systems.

R1 relay examination

The R1 relay was not subjected to overheating and showed no external signs of burning or heat damage.

An X-ray examination showed the misalignment of the A terminals, but did not identify the loose object. The relay was then opened by cutting access holes through the side plates. The B2 terminal contact surface was found to be marked with normal arc spatter and slight sooting and appeared to have been contacting in a slightly misaligned position towards its edge. The terminal insulator on A1 was cracked, with a small piece missing. That piece was found resting at the bottom of the relay casing; its material type does not show under X-ray. The terminal mounting faces had parted, revealing the soldered surfaces between the terminal and its insulator mount. The relay internal components had no evidence of heat damage other than very slight sooting of the B2 terminal.

Each terminal had failed at the point where a flange on the terminal was soldered to the metal collar bonded to a ceramic insulator on the relay casing. Although the A and B pairs of terminals were loose, the solenoid terminals, labelled -X1 and +X2 were intact. The solenoid was heard (and seen under X-ray) to operate when 28 VDC was applied across the X terminals. Examination of the fracture surfaces by binocular microscopy identified what appeared to be solder porosity and areas of mechanical damage in the form of ‘smearing’, indicating rotation of the terminals. It was also found that the surface morphology was consistent with brittle overload. A high magnification picture of the surface is shown in Figure 2. An independent laboratory initially examined the loose terminals and observed

Figure 2

Terminal insulator soldered joint fracture face the characteristics of porosity on the joint faces. However, the component manufacturer considered the brittle overload surface morphology to be the predominant characteristic. A particular example was the B2 stud and terminal insulator interface that showed signs of rotational motion.

The 'B' terminals were straight and could be lifted straight out of the relay. The 'A' terminals were 'cranked' and could not be removed without being excessively destructive. It was considered very likely that the failure mode of all four terminals was the same, so the 'A' terminals were left in place.

Escape slide

The cabin crew initiated a full emergency evacuation, opening the forward cabin doors, which automatically deployed the escape slides. However the Number 1 Right (1R) slide inflated but twisted upside down, becoming jammed against the fuselage and not in contact with the ground. This rendered the slide unusable. The slide was fully inflated and under considerable tension at the top and so for safety reasons the slide was deflated and removed before the AAIB's arrival. Prior to deflation, with the 1R door fully open, it was found that it took very little effort applied at its lower end to right the slide and once righted, it settled in its correctly deployed position. The engineers removing the slide manually took careful note of the girt bar[3] and reported that it was correctly engaged in its fittings. Examination of the slide in its deflated condition off the aircraft found it to be undamaged, despite the twist and tension to its girt bar apron. All the ancillary devices attached to the slide were undamaged. The slide did not appear to have any pre-existent faults or damage. Figure 3 shows that slide in its twisted state prior to removal.

Figure 3

1R slide fully inflated and twisted

Footnote

3 Girt bar – The girt bar is a high strength metal bar attached to the top of the slide. It is clipped into substantial brackets mounted on the cabin door threshold and its purpose is to attach the slide to the aircraft such that in 'automatic'; ie when the cabin door is opened in emergency, the slide self-deploys, ready for use.

Loud hailer

There were two battery powered emergency loud hailers fitted in the overhead lockers; one at the front and one at the rear of the aircraft. The crew reported that they had difficulty using the loud hailer at the front of the aircraft. Examination of the loud hailer (Figure 4) found that, although the unit was fully charged and the press-to-speak handle worked correctly, the volume was set to minimum and the volume control knob was missing. The knob spindle was present and undamaged. The loud hailer fitted at the rear of the aircraft was fully serviceable.

Figure 4

Emergency loud hailer missing volume control knob

Previous incidents and recommendations

Incident to Boeing 737-500, registration EI-CDT

On 20 July 1997, the Danish Air Accident Investigation Board investigated an event to a Boeing 737-500, registration EI-CDT, during which the crew experienced seemingly unconnected cockpit indications, and instrument and system failures. The Board determined that the cause of the event was the failure of the R1 relay associated with the battery busbar, one of the effects of which was to remove power from the equipment cooling fans.

Following the investigation, the Board made two recommendations. The first recommendation related to the performance of the R1 relay in Boeing 737 series aircraft and, in response, the manufacturer issued Service Letter 737-SL-24-120. The Service Letter identified preferred R1 relay part numbers for use in the R1 location. The second recommendation was intended to ensure that Boeing 737 crews would have information readily available to them which would allow them to restore electrical power quickly following a failure of the R1 relay. In response to this recommendation, the manufacturer issued Flight Operations Technical Bulletin 737-300/400/500 98-1, which gave background information on failure of the battery busbar, along with failure indications that could be expected. The bulletin stated that:

> *'The loss of normal EFIS[4] display cooling is not indicated and, thus, the flight crew will not be alerted to accomplish the EQUIPMENT COOLING OFF NNC. Without cooling, the EFIS displays may transition from colour to monochromatic and eventually shut down. This can result in a loss of all attitude information.'*

The bulletin commented that the manufacturer did not consider loss of the battery to be a hazardous situation because normal AC power would provide sufficient instrument indications to flight crew for continued flight and landing. Although the manufacturer had no technical objection to an operator incorporating into its Operations Manual a procedure for the loss of the battery busbar, they were unable to publish a generic procedure in the Boeing Operations Manual because there were many different electrical configurations throughout the Boeing 737 fleet. In circumstances of loss of power to the battery busbar, the only indication common to all aircraft in the 737-300/400/500 fleets would be the loss of N1 engine indications.

Incident to Boeing 737-300, registration G-EZYN

On 22 March 2005, a Boeing 737-300, registration G-EZYN, diverted in flight as a result of symptoms experienced following the loss of power from the battery busbar. An AAIB investigation determined that there had been a failure of the R1 relay[5]. Power to the battery busbar could have been restored by moving the Standby Power switch on the overhead panel from AUTO to BAT, but there was no QRH procedure which would have prompted the crew to carry out this action.

The AAIB commented that, had a relevant procedure been available to the crew, it would have made diagnosis of the problem and decision-making more straightforward, while also restoring the electrical systems that had been affected. The AAIB recommended that the Federal Aviation Administration (FAA) in the USA should require Boeing to examine the electrical configurations of Boeing 737 aircraft, with the intention of providing operators with an Operations Manual procedure to deal with loss of power to the battery busbar.

In its response to the recommendation, the FAA stated that the top-level unsafe condition was the loss of all attitude indications, and the EFIS cooling system did not account for the effects of failure of the R1 relay. It issued FAA Airworthiness Directive (AD) 2009-12-05 mandating corrective actions which were subsequently detailed in Boeing Service Bulletin 737-21A1156, *Air Conditioning – Equipment Cooling System – Electronic Flight Instrument System Cooling Supply Off Light Wiring Change*. The FAA stated that, after the modification to the cooling system, it would be unnecessary to revise the Operations Manual.

Footnote

4 EFIS: Electronic Flight Instrument System.

5 The AAIB report is available here: http://www.aaib.gov.uk/cms_resources.cfm?file=/Boeing%20737-33V,%20G-EZYN%2004-06.pdf

Safety action by the operator

Immediately following this incident, as an interim reminder to crews, the operator reissued an Operating Staff Instruction, *Battery Bus Failure,* originally issued in 2007, which contained Boeing Flight Operations Technical Bulletin 737-98-1 referred to above. Subsequently, the operator incorporated a procedure into its Operations Manual, the objective of which was to confirm failure of the battery busbar and restore power to it if possible (See Appendix 1). In circumstances where the battery bus failed, crews would be directed to select the Standby Power switch to BAT, which should remove symptoms of the failure. Should power not be restored to the busbar, the procedure informed crews of system failures that they should anticipate, including loss of landing gear indications and loss of the PA system. The procedure also directed crews to select the Equipment Cooling Supply switch to ALTERNATE, if necessary, to restore cooling to the EFIS and prevent loss of the electronic attitude display indicator (EADI) and electronic horizontal-situation indicator (EHSI) displays.

Analysis

Operational aspects

This event was triggered by a failure of the R1 relay, for which there was a simple remedial procedure which was not contained within the operator's Operations Manual. The crew diagnosed correctly that there was a problem with the standby power supply and anticipated some of the consequences that would affect them during the landing, ie that the speedbrakes would have to be deployed manually on touchdown and manual braking would be required on the runway. However, the crew did not anticipate that there would be no landing gear indications when the gear was lowered; this led to them going around from the approach because the position of the landing gear could not be determined in the time available. Failure of the R1 relay also led to acrid smoke appearing in the cabin as the aircraft taxied in and the commander's decision to evacuate the aircraft.

Following the incident, the operator added a procedure to its Operations Manual which, in similar circumstances, will direct crews to select the Standby Power switch to BAT to restore power to the battery bus. If this action does not restore power, the procedure prepares the crew for consequential system loss, including the loss of landing gear indications. The procedure also includes action to select the Equipment Cooling Supply to ALTERNATE, if required, to restore cooling to the displays. This addresses the possibility that all attitude information might be lost, which was the FAA top-level safety condition.

The operator's Operations Manual procedure should aid diagnosis and decision-making for crews in similar circumstances while restoring electrical systems that are affected. Understanding in advance that there will be no indication of landing gear position should allow crews to lower the gear early in order to carry out a visual check that it has extended before making the final approach. This should reduce the likelihood that a go-around will be required which, in itself, is an unusual procedure that can provoke errors in crew performance. The procedure should also prevent the situation deteriorating to such an extent that an evacuation becomes necessary, with its attendant increase in risk to passenger safety.

Engineering aspects

Electrical failure

The reproduction of the electrical power distribution system symptoms after the incident and the rectification by replacement of the R1 relay, confirmed the failure of the R1 relay as being causal. In order to lose power to the battery bus there needs to be a loss of continuity between the A or B terminals; for this to happen one or both of the terminal post must be permanently misaligned or become 'out of reach' of the contactor plate. The continuity checks in situ, with power off, (ie the relay in a de-energised condition) were inconclusive, probably due to the terminals being loose.

Forensic examinations by an independent laboratory and by the OEM offered differing conclusions as to why the terminals became loose. There appeared to be evidence of porosity of the soldered joint and brittle overload between its surfaces. However, the difficulty experienced in the disassembly of the terminals and cables means that evidence of these two characteristics could not be relied upon to show the exact failure mode. Furthermore, all the terminals appeared to turn when an undoing torque was applied to the nuts, but exactly how loose each terminal was at the time could not be determined accurately. When the R1 relay was examined in situ, the terminals all appeared to be correctly in place when viewed from the top. However, the position of the relay in the bay made it very difficult to see whether any of the terminals had lifted away from their mountings; in addition the stiffness of the cable harness made everything look and feel tightly assembled.

Despite the exact material failure mode, the loss of the battery bus was due to the loss of electrical continuity across the B1 and B2 terminals, as this is the normal position of the Battery Bus Auto (R1) contacts for the Battery Bus to receive 28V DC from TR-3 before the relay failure. In order for this to happen a misalignment or small movement away from the contactor blade must have taken place. The length of the terminal within the relay would effectively amplify any movement at the cable connection end of the terminal, thus increasing the risk of the loss of contact. The cause of the movement cannot be determined beyond doubt. However, an over-torque on a terminal and the presence of a constant side load or tension from the stiff wiring harness is the most likely scenario to have taken place on one or more of the terminals. It is possible that excessive torque was applied to the terminals at installation or during subsequent maintenance, resulting in a weakening of the terminal insulator soldered joint.

Smoke in the cabin and cockpit area

The crew and passengers became aware of an acrid smell and smoke haze in the cabin and flight deck of the aircraft as they taxied to the stand. Previous incidents have shown that a secondary effect of the R1 relay failure can result in smoke within the cabin and cockpit. The loss of the DC Bus causes the R320 ground sense relay to drop out causing the ACM cooling turbo fans to stop. Without the forced air cooling, the ACM will overheat over a period of time as it is in constant receipt of heated air from the engine compressor. As a result any oil residue and dust within the ACM and ducts will start to produce vapour, smoke and fumes. The examination of the ACMs showed that the lubricating oil in the sight glasses appeared to be discoloured and overheated indicating the possibility of heat distress. It was reported that the passengers become aware of the acrid smell and smoke in the cabin after landing during the taxi to the stand. The design of the air conditioning system within the Boeing 737, and many other similar aircraft types, means that there is a natural increased air movement, followed by stagnation of air within the aircraft cabin as the system resets to the aircraft being on the ground and as the aircraft and its systems are shut down. Taking into consideration the source of the smoke it would be normal, although disconcerting for passengers, for acrid air in the ACM ducts to move and collect within the cabin as a smoke haze.

Escape slide

Examination of the 1R door escape slide and girt bar after the incident revealed that it was correctly attached to the aircraft and therefore was in its automatic position. The slide material and its inflation equipment were undamaged and there was no evidence of a pre-existent fault. There did not appear to be a technical reason why the slide became twisted during deployment, but anecdotal evidence suggests that there have been previous occasional mis-deployments of the slides. Of those, the majority seem to have taken place with the right front cabin door; ie the 1R slide, as in this case. It is not clear exactly how these mis-deployments occur. In some cases the doors have been observed not to be completely clear of the slide as it deploys and so can deflect the slide while partially inflated. A twist then sets in at the top, then, as the moment (ie length and leverage of the inflating slide) increases with extension, the twist tightens and remains in place. When this happens, the resulting twist causes the slide to adopt a highly unusual angle and places the bustle apron under extreme tension, as was found in this case. A possible reason why the 1R door may not be clear in time is that the cabin crew two-handed muscular auto-motor skills are more used to opening the Number 1 Left (1L) door in one smooth, well-practiced movement. Research and discussion at a UK-based Boeing 737 cabin crew simulator suggested this was a distinct possibility.

Loud hailer

The cabin crew reported difficulties with the handheld emergency load hailer at the front of the aircraft. The volume was turned down and the knob was missing, leaving the end of the spindle to which it was attached below the level of the casing. It was unclear how, or when, the knob came to be missing and a search of the overhead locker in which the hailer was stowed failed to locate the missing item.

Conclusion

The electrical difficulties experienced in this aircraft were as a direct result of the loss of continuity between the R1 relay terminals. This was due to one of its terminals loosening in its insulated mounting over an indeterminate period of time and moving away from the contactor, thus breaking continuity. It is possible that this was caused by an overtightened terminal nut weakening the terminal and insulator soldered joint whilst at the same time being under a degree of tension or side load from the heavy gauge electrical cables.

Appendix 1

Operator's procedure for Battery Bus Failure

Battery Bus Failure

Condition: Blanking of BOTH N1 gauges. Multiple failures of items connected to the Battery Bus, caused by Bus failure

Objective: Confirm bus failure, attempt to restore bus power

Note: No single light or message will indicate a battery bus failure

1 Choose one:

- With BAT BUS selected on the DC Metering Panel, Volts and Amps indications are erratic or indicate zero (0):

  Go to step 2

- With BAT BUS selected on the DC Metering Panel, Volts and Amps indications are **not** erratic or indicate zero (0):

  Complete other QRH checklists as appropriate

■ ■ ■ ■

2 STANDBY POWER switch.....BAT

3 Choose one:

- With BAT BUS selected on the DC Metering Panel, Volts and Amps indications remain erratic or zero (0):

  Go to step 4

- With BAT BUS selected on the DC Metering Panel, Volts and Amps indications are **not** erratic or indicate zero (0):

  The battery is continuously charged. To avoid potential overheating of the battery, consider landing at the nearest suitable airport

■ ■ ■ ■

4 STANDBY POWER switch.....AUTO

5 EQUIP COOLING SUPPLY switch.....ALTERNATE

This restores EFIS Cooling and prevents loss of EADI and EHSI displays

6 Land at the nearest suitable airport.

Note: System functions and indications may not be normal. Affected major systems and indications vary and include (but are not limited to):

Indications:

Master Caution annunciation
Engine parameters (e.g. N1)
Landing gear lights
Aural Warnings
Standby Attitude Indicator
Pressurization status

Systems:

Passenger Address (PA)
Engine and Wing Anti-Ice control
Thrust reverser control
Inboard Antiskid
Parking brake control
Passenger Oxygen System
Pack valve control
Engine fire detection
APU ignition
Fuel crossfeed control