INCIDENT

Aircraft Type and Registration:	Boeing 737-33V, G-EZYN
No & Type of Engines:	2 CFM56-3C1 turbofan engines
Year of Manufacture:	1999
Date & Time (UTC):	22 March 2005 at 1050 hrs
Location:	Near Lyons, France
Type of Flight:	Public Transport (Passenger)
Persons on Board:	Crew - 5 Passengers - 110
Injuries:	Crew - None Passengers - None
Nature of Damage:	None
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	46 years
Commander's Flying Experience:	5,555 hours (of which 5,355 were on type) Last 90 days - 211 hours Last 28 days - 88 hours
Information Source:	AAIB Field Investigation

Synopsis

During a flight from Nice to Luton, the flight crew experienced progressive abnormal annunciator indications. For some of these there were no procedures in the Quick Reference Handbook. Having determined that these indications were a symptom of a greater electrical problem, including degradation of their flight instruments and loss of protection systems, a PAN call was declared and a diversion to Lyons initiated where an uneventful landing was made. The subsequent investigation revealed that a failure of a contact post had occurred in the R1 relay associated with the Battery Busbar, and that power had been lost from this Busbar in flight. There were no drills published for such a failure on this model of the Boeing 737. With this failure there is a risk that, due to the loss of power to the equipment cooling fans, all attitude information could eventually be lost if power is not switched to an alternate supply. The many different configurations of the electrical system in the Boeing 737-300/400/500 fleet have made it difficult for the manufacturer to produce a generic procedure for this failure, although they have provided information to enable operators to write a procedure for their own aircraft. One safety recommendation is made.

History of the flight

The aircraft departed Nice en-route for Luton and had been cleared to climb to FL360. As it passed FL340 the flight crew noticed SPD LIM annunciators on both Electronic Attitude Director Indicators (EADIs). In the absence of any Quick Reference Handbook (QRH) procedure for this indication, the crew continued the climb, looked for other abnormal signs and checked the circuit breakers. Three amber lights, for SPEED TRIM FAIL, MACH TRIM FAIL and AUTO-SLAT FAIL, were visible on the left System Annunciator Light Panel on the glare shield; however, the MASTER CAUTION light was not illuminated. The crew checked the hydraulic indications, which were normal, but observed that both engine N1 and fuel flow gauges were blank and that the WXR FAIL annunciator was displayed on the Electronic Horizontal Situation Indicators (EHSIs). They completed the QRH procedures for the three amber lights and noted that the aircraft was limited to a speed of 0.74 Mach, as a consequence of the MACH TRIM FAIL indication. The crew requested a descent to FL300, informing ATC that they had a technical problem. The commander stated that the Minimum Manoeuvre Speed (MMS) indication had disappeared from the EADIs and flight at FL360 gave a narrow buffet margin, whilst descent to a lower level would give the aircraft a greater margin at a speed of 0.74 Mach.

At this stage, the crew realised that the failures must be linked to a more general electrical system problem. During the descent, the Standby Attitude Indicator (AI) began to topple, followed shortly by the loss of background colour from both the commander's and co-pilot's EADIs. The crew recognised this as an indication of the loss of the cooling system to these units. Because the crew were concerned that this would, in time, be followed by complete EADI display failure, they selected the Equipment Cooling Supply and Exhaust switches from Normal to Alternate, despite the fact that the amber Equipment Cooling OFF lights were not illuminated. After a few seconds background colour was restored to the EADIs.

The aircraft's electrical system was checked using the AC and DC Metering Panel and the flight crew noted that there was no output from the Battery Busbar (Bus) and Static Inverter, while the other readings were normal. There being no abnormal procedure for these failures, the crew elected to divert immediately to Lyons (Satolas); the nearest major airfield. The commander stated that their decision was made due to the lack of engine fire detection and indication systems, as a result of no output from the Battery Bus, the toppling of the Standby AI and the fact that the aircraft systems were not operating normally.

The commander took control as pilot flying (PF) and a PAN call was declared. Because he was unsure of the continuing status of the aircraft's electrical systems, and feared losing the main EADIs in the Instrument Meteorological Conditions (IMC) that prevailed at the time, the commander expedited the descent until the crew were established in Visual Meteorological Conditions (VMC). During the diversion the Senior Cabin Crew Member (SCCM) knocked on the Flight Deck door and, on being let in, informed the flight crew that all Passenger Address (PA) and interphone communications in the cabin were inoperative. The commander briefed the SCCM on the problem, and their intentions, and instructed him to prepare for a precautionary landing. Thereafter the flight deck door remained unlocked. The cabin crew individually briefed the passengers and the commander attempted to make an announcement from the flight deck over the PA system, without success.

At some stage during the diversion the flight crew noticed that the flight deck clocks had failed and the co-pilot recalled seeing a blue COWL VALVE OPEN light for the right engine, although the commander did not remember discussing this with him at the time.

The autopilot and autothrottle were operating normally so the crew left them engaged throughout to reduce their workload. They established VMC at an altitude of 4,000 ft amsl and ATC gave them radar vectors for an Instrument Landing System (ILS) approach to Runway 18L at Lyons. When the aircraft was established on the localiser the crew found that they could not arm the autobrakes and discussed the need for manual braking. They also checked that there was sufficient runway for landing in such circumstances.

On selecting the landing gear down, the crew only received a red nose wheel 'disagreement' light. They requested an over-flight of the runway at an altitude of 2,000 ft amsl and asked ATC to visually check that the landing gear had extended. ATC confirmed that they could see that it had extended and the crew then requested radar vectors for another ILS approach to the same runway. This gave time for the co-pilot to check the 'Main and Nose Gear Viewers', in the cabin and on the flight deck respectively, to confirm that the landing gear was locked down, which it was.

The aircraft established on the localiser for the second time and, when it captured the ILS glideslope, all the aircraft's electrical systems returned to normal and the failure indications cleared. The commander then disengaged the autopilot and flew the aircraft manually. After an uneventful landing, the commander made a reassuring PA to the passengers. The Airport Fire Service, who had attended the landing, were stood down and the aircraft was taxied on to a stand and shut down without further incident.

Battery Bus description

A schematic diagram of the aircraft electrical system is shown at Figure 1, where the battery relays are in the area enclosed by the dashed line. Additional detail of the 28 volt DC system is shown at Figure 2, where it can be seen that the Battery Bus is supplied from the Transformer-Rectifier Unit (TRU) No 3. In the event of a main AC failure, the DC and AC elements of the Standby power system are supplied by the Battery Bus and static inverter respectively.

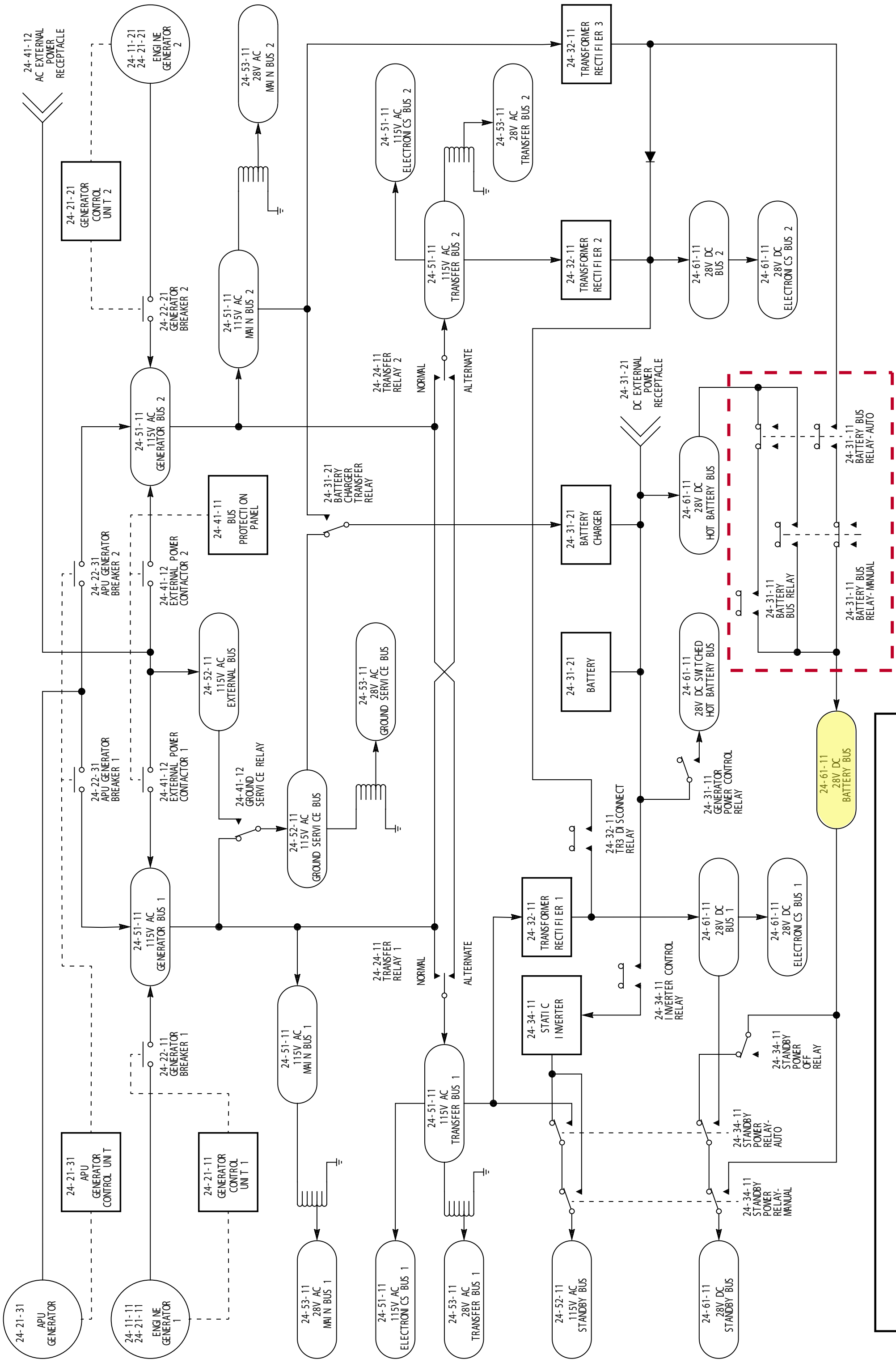
Investigation of the aircraft

Following the incident, the operator contacted the aircraft manufacturer for assistance, who, after analysis of the crew reports, suggested that a fault may have occurred in the 'R1' or 'R326' relays.

These relays are in the circuit that supplies power to the Battery Bus. The R1 relay was replaced and the appropriate checks indicated that the electrical systems were operating normally; accordingly, the aircraft was returned to service. The removed component was sent to a UK maintenance organisation for investigation. On receipt, the relay was, unusually, found to rattle. When tested, the switching operations were audible, but the A1 and A2 contacts (refer to Figure 2) remained open circuit. An internal inspection revealed that a contact post had broken off, possibly as a result of a fatigue process associated with the stresses of the contacts opening and closing. The relay had been on the aircraft since its delivery in 1989, since when it had achieved 16,680 flight hours.

Effect of relay failure on aircraft systems

The loss of the Battery Bus would result in the immediate loss of all connected systems, although the impression given by the crew was one of progressive failures. This may simply have been an issue of perception, as there would have necessarily been a time lag between the loss of power and, for example, the toppling of the internal gyroscope in the Standby Attitude Indicator. Similarly, the loss of colour on the



NOTE: Switch/relay contact positions shown for aircraft on the ground, electrical power OFF

Schematic reproduced by kind permission of Boeing

Figure 1

Boeing 737-300/400/500 Electrical Schematic

Page 24-00-01, Boeing Systems Schematic Manual

EADIs would have occurred as a result of the loss of the power supply to the equipment cooling fans. In such an event, according to the aircraft Maintenance Manual (AMM), low airflow sensors within the cooling ducts send a signal to the symbol generators, which inhibits the EADI raster display, thus reducing the heat generated. The effect of this is to remove the colour, although the EADIs and EHSIs will continue to operate in monochromatic mode. In addition, the weather radar display is removed from the EHSIs, resulting in a WXR DSPLY annunciation. In the event of an overheat condition, temperature sensors on the EADI's and the EHSI's also cause a discrete signal to be sent to the symbol generators, with the same result. According to the AMM, in the event that the temperature continues to rise for any reason, the displays will shut down although, in fact, they are designed to operate for a minimum of 90 minutes without cooling. The above symptoms were exactly as the crew reported and, moreover, when the equipment cooling fan power supply was selected to 'ALTERNATE', the displays returned to normal. This occurred "within a few seconds", as the airflow sensors registered the restored flow and removed the raster inhibit signal to the symbol generators.

The loss of the Battery Bus results in the loss of, among others, the Master Caution and the engine fire detection and indication systems, although the fire extinguishing function remains available via the Hot Battery Bus[1]. The inverter control relay would also unlatch, causing the loss of the inverter AC output. On this particular aircraft, the Standby Attitude Indicator is DC powered from the Battery Bus, with an integral inverter providing its AC requirements. As a result of customer options, some 737 aircraft are equipped with a different type of instrument, one that is powered directly from the AC Standby Bus and would thus remain unaffected by the loss of the Battery Bus.

The restoration of the electrical systems, following glideslope capture, may have been a coincidence, as well as being indicative of the intermittent nature of the fault during the final separation of the relay contact post. The DC Buses 1 and 2 are normally connected in parallel, until the Flight Control Computer (FCC) sends a Bus isolation command. This opens the TR3 disconnect relay in Figure 1, in preparation for an autoland, thereby creating two separate DC power supplies as is required for this procedure. Glideslope capture is one of several parameters that must be met before the FCC sends the isolation command. Although this may have altered the load on the DC buses, the R1 relay is on the Battery Bus and should not be affected by the FCC command.

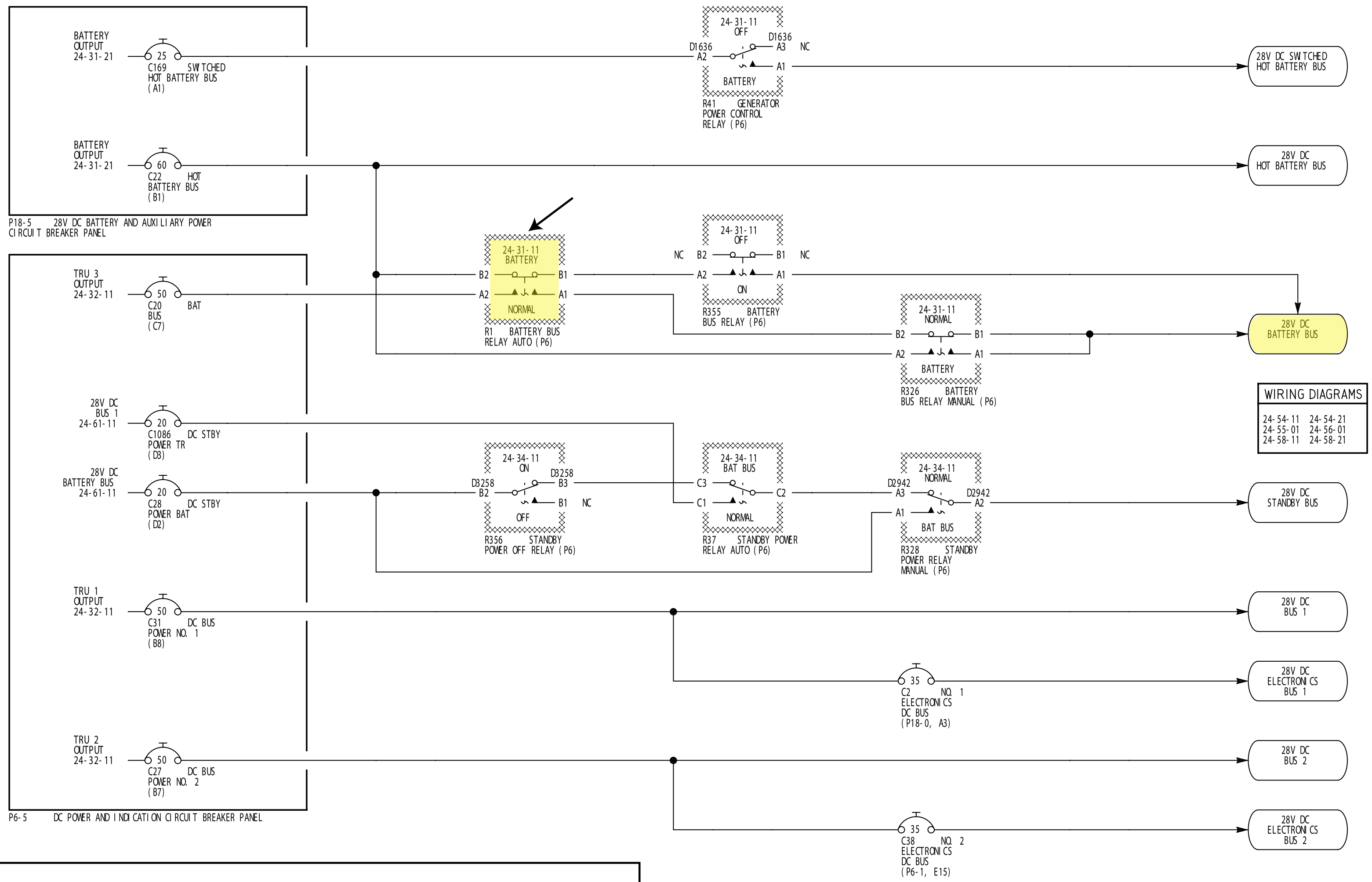
In this incident, the battery and its charging system, remained unaffected and power to the Battery Bus could have been restored by moving the Standby Power switch on the overhead panel from the 'AUTO' to the 'BAT' position.

Flight Operations Technical Bulletin Number 737-300/400/500 98-1

On 20 July 1997, the Danish Air Accident Investigation Board investigated a similar event to a Boeing 737-500, EI-CDT, where the Battery Bus failed and the crew were presented with apparently 'unconnected' cockpit warnings/indications and some instrument and systems failures. The cause of the problem on that occasion was established as a failure of the R1 relay. Two Safety recommendations were made to the Danish Authorities, as follows:

Footnote

[1] The hot Battery Bus is hard wired, through a circuit breaker, directly to the battery.



NOTE: Switch/relay contact positions shown for aircraft on the ground, electrical power OFF

Schematic reproduced by kind permission of Boeing

Figure 2

Boeing 737-300/400/500 Electrical Schematic 28V DC Power Distribution

Page 24-61-11, Boeing System Schematic Manual *'a 'The Civil Aviation Administration takes the necessary actions to seek a reevaluation of the performance of the Battery Bus Relay (R1) in its installation in the Boeing 737 series aircraft to ensure proper function. (REC-04-97)*

b The Civil Aviation Administration takes the necessary action to ensure that the crew of Boeing 737 aircraft has the proper information readily available to quickly restore the electrical power supply in the event of the failure of the Battery Bus Relay (R1). (REC-05-97)'

The report noted that the Battery Bus on that aircraft supplied current to 56 essential systems.

In response to recommendation 'a', the manufacturer issued Service Letter 737-SL-24-120 concerning *Battery/Standby/DC Power System Relays – Preferred Spare'.* In this letter, the manufacturer identifies relays with specific part numbers that they recommend be used in the R1 location.

In response to recommendation 'b', the manufacturer issued Flight Operations Technical Bulletin 737-300/400/500 98-1 concerning *'Battery Bus Failure.'*

This Bulletin was issued on 4 August 1998 and applied to all Boeing 737-300/400/500 aircraft. The relevant text is reproduced below:

'SUBJECT : *Battery Bus Failure*

Background

Over the last few years several operators have reported in-flight loss of battery bus due to electrical system relay failures. Relay contacts have electrically opened and/or arced, resulting in loss of, or erratic voltage on, the battery bus.

Several improvements have been made to these relays to improve their reliability and eliminate poor electrical contact performance. Despite improvements these relays still occasionally fail. The Boeing data base contains 8 failures since 1990, three of those since 1994.

Failure Indications

737-600/700/800

The STANDBY POWER OFF light illumination indicates one or more of the following busses are unpowered: AC Standby bus, DC Standby bus, or Battery bus. The QRH procedure calls for taking the Standby Power Switch to --- Bat.

737-300/400/500

The STANDBY POWER OFF light will only illuminate for loss of the AC Standby bus. No light or message will tell the flight crew that the Battery Bus has failed. The only indication to the crew that this failure has occurred is the loss of various instrument indications or observing a zero indication on the BAT BUS DC Meters. These instrument indications will vary depending on specific airplane options installed and phase of flight. For example: the Standby Attitude Indicator may fail; the Landing Gear down green lights will be inoperative, but the crew will not see this until the landing gear is lowered.

All 737-300/400/500's will lose at least 1 primary engine display.

The following matrix shows which bus powers the primary engine displays for both EIS (electronic indication system) and Non EIS airplanes.

Parameter	*Non EIS*	*EIS*
N1	***BAT***	***BAT***
N2	*Main or STBY*	*STBY*
EGT	***BAT** or STBY*	*STBY*
FF	*MAIN*	***BAT***

Operating Information

In the past, Boeing has not written Non-Normal procedures unless there is a Master Caution or specific light which indicates the problem. Loss of only the battery bus is not considered a hazardous situation. Normal AC power will provide sufficient instrument indications to the aircrew for continued safe flight and landing.

If an operator wants to provide its aircrews with a procedure to cover a relay failure resulting in loss of the Battery bus, the following information is provided as a starting point.

Loss of both engine N1 indicators is the only indication of a Battery bus failure common to all 737-300/400/500 airplanes. Most airplanes will lose an additional primary engine indication (see matrix above). Additional indications will vary depending on the specific electrical configuration of the airplane. Once a Battery bus failure is suspected, it should be confirmed with the overhead DC indicators. Once confirmed, taking the Standby Bus Switch to BAT should restore the Battery bus. With one or both Generator Busses powered and the Standby Power Switch selected to BAT, the Battery Charger will supply power to the Battery indefinitely.

Boeing has no technical objection to an airline incorporating a loss of Battery Bus procedure in their Operations Manual. However, since there are so many different electrical configurations throughout the 737 fleet, Boeing is unable to publish a generic procedure in the Boeing Operations Manual which will work for all 737-300/400/500 airplanes.'

Other information

According to the aircraft manufacturer, the subject relay type is used in five locations throughout the electrical system, although they are each given separate designations. Although there are around 5,000 aircraft in the world-wide fleet that use this relay, only 2,829 B737 aircraft use this relay to power the DC Battery Bus and, of these, 1,425 aircraft (B737-3/4/500 with EFIS displays and DC Standby Attitude Indicators) are likely to be affected in a similar manner to G-EZYN should the R1 relay fail. To date, a number of relay failures have occurred leading, in some cases, to the in-flight loss of the Battery Bus. The aircraft manufacturer has stated that loss of the Battery Bus not only results in loss of the equipment cooling fans but also loss of the equipment cooling warning light function. Since this incident, the manufacturer has committed to releasing an Alert Service Bulletin in the 2nd quarter of 2006 to change the wiring of the EFIS cooling warning circuit to a different DC Bus.

In the United Kingdom, the Civil Aviation Authority (CAA) has reported the incident to the Boeing 737 Project Certification Manager at the European Aviation Safety Agency (EASA), with a request that the incident be reviewed by the Federal Aviation Administration (FAA). The FAA should advise on whether further action, in the form of a Flight Manual amendment or system modification, should be considered.

Discussion

The failure of the R1 relay resulted, as with the previous event to EI-CDT, in the Battery Bus becoming de-powered, with consequential loss of a number of systems. The flight crew carried out the QRH drills for indicated failures of the speed trim, Mach trim and auto-slat systems but, following the loss of some indicated engine parameters, realised that a more general electrical failure had occurred. The loss of colour on the EADI's was remedied by switching the equipment cooling fan switches to 'ALTERNATE', and the crew were aware of the possibility that the screens could shut down completely due to high temperatures had they not done so. Following the loss of the Standby Attitude indicator, this would have resulted in the loss of all attitude indication. In the light of this, the assertion in the Flight Operations Technical Bulletin that: '*Loss of only the battery bus is not considered a hazardous situation*' is perhaps questionable. This statement was perhaps appropriate to the design of the system as intended, but the subject incident has led the manufacturer to understand that an unforeseen situation can arise. By releasing an Alert Service Bulletin early in 2006, which will change the wiring of the EFIS cooling warning circuit to a different DC Bus on affected aircraft, this warning will not be lost in the event of the DC Battery Bus being unavailable and hence the crew should be prompted to switch to alternate EFIS cooling and maintain their primary attitude reference. The DC powered Standby Attitude Indicator would remain unavailable under these circumstances.

Checklist procedures for electrical system malfunctions cannot reasonably be expected to cater for failures of individual components down to relay level, so the crew were left to conduct their own diagnosis. This they did successfully, to the extent that they identified zero volts on the Battery Bus and the static inverter. However, there were no drills for this condition so they took no additional action, although normal operation, at least on this aircraft, could have been restored by moving the Standby Power switch to the 'BAT' position. This is recognised in the Technical Bulletin, which gives operators the option of incorporating a procedure in their Operations Manual. The manufacturer, however, has not published a generic procedure due to the fact that "there are so many different electrical configurations throughout the worldwide Boeing 737 fleet".

The proposed modification to the electrical system by the manufacturer, should provide a means to preserve the main attitude displays following the loss of the Battery Bus, although it is not known at this point if it will address the loss of other significant systems, such as engine fire detection and indication.

Safety Recommendations

The loss of the Battery Bus on Boeing 737-300/400/500 aircraft results in the loss of a number of significant systems which, on some aircraft, can include the Standby Attitude Indicator. The integrity of the main attitude displays on EFIS equipped aircraft can also be compromised due to the loss of cooling. The flight crew in this incident dealt with the situation effectively, using the procedures available and their knowledge of the aircraft. There is no doubt that a specific procedure for the problem, had one been available to them, would have made diagnosis, crew actions and subsequent decisions significantly more straightforward, while also restoring the aircraft's affected electrical systems. Indeed, the crew may have considered that a diversion to Lyons may not have been necessary. A different crew, however, may not have reacted to the situation in a similar manner, with an attendant risk that loss of all attitude information could have occurred.

After this event, the operator amended its Operations Manual to incorporate such a procedure, subject to their aircraft being of a suitable electrical configuration. It is not clear, however, what the consequences would be of conducting a 'loss of Battery Bus procedure' on an aircraft with an 'inappropriate' configuration.

As a result of this incident, the following Safety Recommendation has been made:

Safety Recommendation 2005-65

It is recommended that the Federal Aviation Administration require that the Boeing Airplane Company examine the various electrical configurations of in-service Boeing 737 aircraft with the intention of providing operators with an Operations Manual Procedure that deals with loss of power from the Battery Busbar.