SERIOUS INCIDENT

Aircraft Type and Registration:	Boeing 737-4Q8, G-JMCR
No & Type of Engines:	2 CFM56-3C1 turbofan engines
Year of Manufacture:	1992 (Serial no: 25372)
Date & Time (UTC):	12 October 2018 at 0155 hrs
Location:	En-route to East Midlands Airport
Type of Flight:	Commercial Air Transport (Cargo)
Persons on Board:	Crew - 2 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	None reported
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	50 years
Commander's Flying Experience:	8,418 hours (of which 6,314 were on type) Last 90 days - 112 hours Last 28 days - 46 hours
Information Source:	AAIB Field Investigation

Synopsis

The aircraft was operating a night flight to East Midlands Airport, with the left engine generator disconnected, and had just commenced its descent when the crew faced an unusual array of electrical failures on the flight deck. Despite the loss and degradation of a number of systems, the aircraft landed safely at East Midlands.

The electrical failures were caused by the right engine Generator Control Unit (GCU) which had been incorrectly secured in its mounting tray and had disconnected in flight. The investigation also uncovered a number of contributory factors including: the management of defects and Acceptable Deferred Defects (ADD), recording of maintenance, and a number of weaknesses in the operator's Safety Management System with regards to managing risk.

Five Safety Recommendations are made to the operator regarding its safety management system and one to the Civil Aviation Authority.

History of the flight

The crew reported for work at Leipzig Halle Airport, Germany, on the evening of 11 October 2018. They were rostered to operate a three-sector day from Leipzig to Amsterdam Schiphol Airport, then to East Midlands Airport and finally to Aberdeen Airport.

On arrival at the aircraft, the crew met with the pilots who had flown the aircraft into Leipzig and briefly discussed that the aircraft was operating with an ADD for an inoperative Gen 1. The aircraft was permitted to operate under Minimum Equipment List (MEL) 24-1b providing the APU, and its generator, were run during the flight. In this condition the No 1 electrical system was powered by the APU generator and the No 2 system by the engine-driven generator on the right engine (Gen 2).

At 2243 hrs, the aircraft departed from Leipzig and the flight was without incident until the landing at Amsterdam when the co-pilot's flight instruments, which are powered by the No 2 electrical system, intermittently blanked and several electrical warning lights on the overhead panel illuminated intermittently. The crew were unable to determine the cause of the problem and concluded that Gen 2 had failed, leaving the APU generator providing the only electrical power to the AC busses. They attempted to select the APU generator to provide power to the No 2 electrical system, but it would not connect. The aircraft was taxied to the parking stand and shut down.

The crew were aware that the MEL did not allow the aircraft to dispatch with only a single generator functioning and, therefore, the crew contacted the operator's Line Maintenance Control (LMC) who arranged for an engineer in Amsterdam to attend the aircraft. After around 30 minutes, the engineer arrived at the aircraft and was briefed by the commander. He was seen to open the cowlings on the right engine in order to examine Gen 2; he also checked the relevant circuit breakers and Panel M238 on the sidewall of the cockpit. The engineer informed the crew that he had reset a circuit breaker and was confident that this was the cause of the problem but would require the right engine to be run in order to ensure that the engine generator was working correctly. The engine run was performed satisfactorily and the generator on the right engine and the No 2 electrical system worked normally. The engineer cleared the entry in the aircraft technical log and as part of their pre-flight preparation the crew discussed the actions they might take in the event they lost the remaining engine generator. The aircraft departed Amsterdam with the original ADD for an inoperative Gen 1.

The flight was without incident until the aircraft was approximately 60 nm from East Midlands, with the co-pilot as PF, when during the descent the autopilot disconnected, the co-pilot's screens lost power and his flight instruments failed. The commander took control and disconnected the autothrottle as he was flying the aircraft manually. Numerous lights on the overhead panel and system annunciation panels illuminated and flashed, and multiple aural warnings were generated by the Terrain Avoiding Warning System (TAWS). As both crew members were visual with the runway, the commander instructed the co-pilot to make a PAN call and ask for vectors straight onto the ILS at East Midlands. During the next 20 minutes, and until the aircraft landed, the flight instruments on the co-pilot's side came on and off numerous times.

The commander manually flew an ILS approach onto Runway 27. The aircraft controls, flaps and gear worked normally although the distracting flashing warning lights and aural callouts continued throughout the approach. On landing, numerous aircraft systems failed including the autobrakes (although manual braking remained available), half the exterior lights and the commander's speed indications on his electronic attitude display indicator. On reaching the stand, the crew were unable to connect the electrical ground power to the aircraft system. While the flaps were retracted, the flap indication showed them still deployed. No electrical power was available to the cargo door, cargo bay and multiple items on the flight deck.

The crew briefed the ground engineers and completed the technical log before continuing to Aberdeen on a replacement aircraft. The engineers later discovered that the GCU for Gen 2, which is located in the flight deck behind the right pilot seat, was not correctly fitted in its housing.

Recorded information

The aircraft's flight data recorder (FDR) and cockpit voice recorder (CVR) were removed from the aircraft and downloaded at the AAIB where their recorded information was analysed. The duration of the CVR was 30 minutes and the recording started about 5 minutes before the descent into East Midlands. The FDR recorded just over 52 hours of data; however, there were no parameters associated with the aircraft's electrical system that were of use to the investigation.

Airfield information

East Midlands has a 2,863 m long runway and was long enough for G-JMCR to stop with a complete brake failure using the other available retardation devices.

Meteorology

The weather for the route from Amsterdam to East Midlands was relatively clear with little cloud forecast during the night, although the weather was expected to deteriorate markedly during the day. The weather observations at East Midlands during the event reported a clear night with scattered or broken cloud at 1,300 ft aal.

Organisational information

The operator was part of a parent organisation that operated out of the UK and Sweden with the UK group operating a fleet of Boeing 737 aircraft. The Air Operators Certificate (AOC) and EASA Part M[1] for the Boeing 737 was held in the UK. In the 18 months prior to the incident, the UK fleet increased from 11 to 17 aircraft and by the beginning of June 2019 had increased to 21 aircraft with a corresponding increase in staff. During this period the operator's main operating base moved from Coventry Airport to East Midlands. The administration of the AOC and its Part M responsibilities also moved from Coventry Airport, to a nearby business park.

The operator has an extensive European network with engineering support provided by fixed base contracts supported by EASA Part 145[2] organisations. When aircraft are required to operate to other non-standard locations, the aircraft is supported with either on-board engineers or short-term temporary line support contracts with Part 145 organisations.

Footnote

1 Commission Regulation (EU) No 1321/2014 of 26 November 2014 on the continuing airworthiness of aircraft and aeronautical products, parts and appliances, and on the approval of organisations and personnel involved in these tasks Annex I Part M.

2 Commission Regulation (EU) No 1321/2014 of 26 November 2014 on the continuing airworthiness of aircraft and aeronautical products, parts and appliances, and on the approval of organisations and personnel involved in these tasks Annex II Part 145.

All line maintenance defects, rectification action and certification are recorded on the appropriate Sector Record Page (SRP) in the aircraft technical log and controlled by LMC which is also located at East Midlands. The operator uses a Flight Status Reporting system (FSR) that allows defects and daily aircraft status information to be recorded by line maintenance engineers through an on-line portal. This replicates the information on the SRP and provides troubleshooting feedback and a messaging system that provides the LMC engineers with immediate and relevant information. Flight crew have access to the FSR when operating down route through a tablet device.

A group audit carried out in May 2018 identified issues with the level of competence of the staff in LMC, which resulted in the establishment of an LMC Manager post who took over the management functions from the Operations Manager and placed LMC under the Part M organisation. The LMC procedures were also revised and additional staff training was planned. This process was ongoing at the time of the event. It was also decided to create the post of Defect Controller to manage the ADD and MEL entries; this individual reported directly to the Maintenance Manager. A contractor was initially employed in this post from 18 June 2018 while a suitable candidate was recruited; however, the contractor had to leave on 24 September 2018 and the position was vacant when the incident occurred.

Of the 15 engineers who worked in LMC, two were employed on each shift, with an additional person providing logistical support. Oversight was exercised by the Operations Shift Supervisor (Figure 1). During the normal working week, a conference call involving representatives from the LMC and the Part M organisations in the UK and Sweden took place at 0600 hrs each morning to review what had happened overnight. In January 2019, following this event, the operator introduced an additional conference call at 0815 hrs that included representatives up to the Accountable Manager from the operation, technical and business areas of the company. However, neither of these conference calls takes place at the weekends or public holidays.

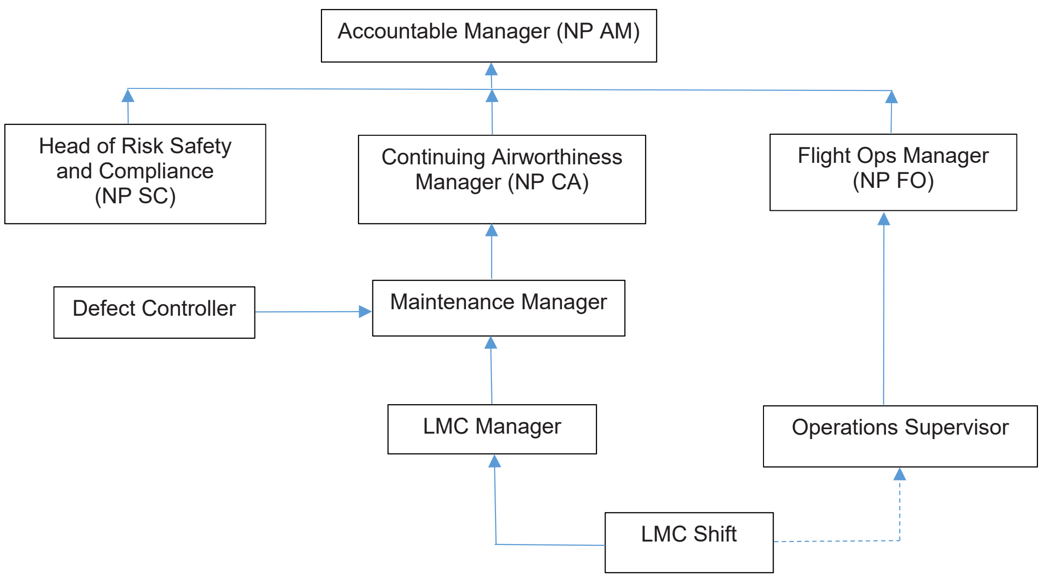

Figure 1
Organisational diagram

Aircraft information

G-JMCR is a Boeing 737-400 freighter aircraft. Its Certificate of Airworthiness was issued on 4 August 2014 and the Airworthiness Review Certificate was valid until 4 August 2019.

The last significant scheduled maintenance was a 'C' check that was completed on 8 March 2018 at a Part 145 organisation based at Norwich Airport. No problems were experienced with the electrical power system and none of the GCUs were recorded as having been disturbed during the maintenance.

Systems description

General

In the B737-400, AC electrical power is provided by one generator fitted to each engine through a Constant Speed Drive Unit (CSDU) and one generator connected to the APU. The normal configuration inflight is for each of the engine-driven generators to power one of two 115V AC generator busses (Gen Bus 1 or 2). If one generator is inoperative, the APU generator may be used to power the inoperative generator's bus. In the air, the APU generator can only power one of the generator busses, whereas on the ground it can power both. One generator (engine-driven or APU) can provide sufficient power for all essential flight systems. A schematic of the electrical power system is at Figure 2.

AC power supply

The AC power supply consists of two systems identified as 1 and 2 with system 1 powering the flight instruments on the left side of the flight deck and system 2 the right side. Each generator is connected to a Gen Bus (1 or 2) and a Transfer Bus (1 or 2). The Transfer Busses normally receive their power from their respective Gen Bus and have an associated Transfer Relay which automatically selects the opposite Gen Bus as a power source if its Gen Bus loses power. At the same time the protective automatic load-shedding circuit turns off all power to the aircraft galleys to ensure that the remaining generator is not overloaded.

The GCU monitors itself for correct voltage, frequency, ground faults in the generator or excessive current draw from any generator. If any malfunction develops, the GCU will detect the fault and disconnect the generator from its generator bus.

Generator malfunction lights

Panel M238, which is located in the entrance to the cockpit, contains four white generator malfunction lights for each generator: High Voltage (HV), Low Voltage (LV), Feeder Fault (FF) and Manual Trip (MT). These warning lights are controlled by double-coil relays inside each of the GCUs and once energised will be latched in the TRIP position by a permanent magnetic latch. The HV, LV and FF malfunctioning lights can be reset by pressing the ERASE button located on Panel M238.

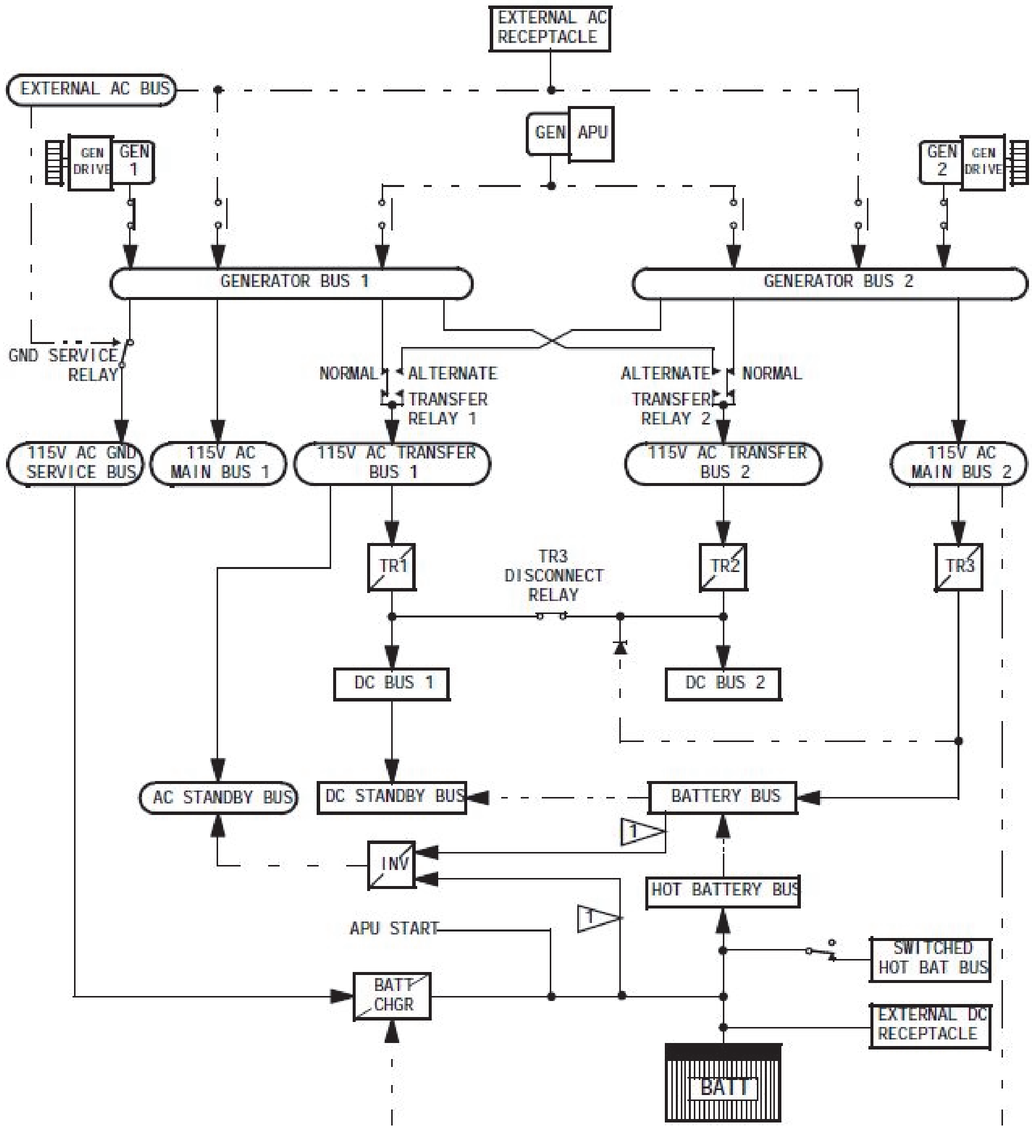

Figure 2

Schematic of electrical power system

Generator Control Unit

Each generator is controlled by its own GCU located in panel P6 located behind the right pilot seat. The effect of GCU 2 becoming disconnected in flight, which is described in Appendix 1, would be the loss of the following busses:

- 115V AC Main Bus 2
- 115V AC Transfer Bus 2
- 115V AC Electronic Bus 2
- 28V DC Bus 2
- 28V DC Electronic Bus 2

Racking of Generator Control Unit

The GCUs are mounted in the electrical equipment rack and are fitted by sliding the unit rearwards into the tray with the handle lever in the open position and ensuring that the guide pins at the back of the tray engage in the frame (Figure 3). Once the unit has been pushed in far enough, the hook at the bottom of the handle lever will engage with the fork assembly that is attached to the shelf. The handle lever is then moved into the locking detent securing the box in the tray. The Aircraft Maintenance Manual[3] (AMM) provides further instructions to ensure that the handle and fork assembly have been correctly adjusted.

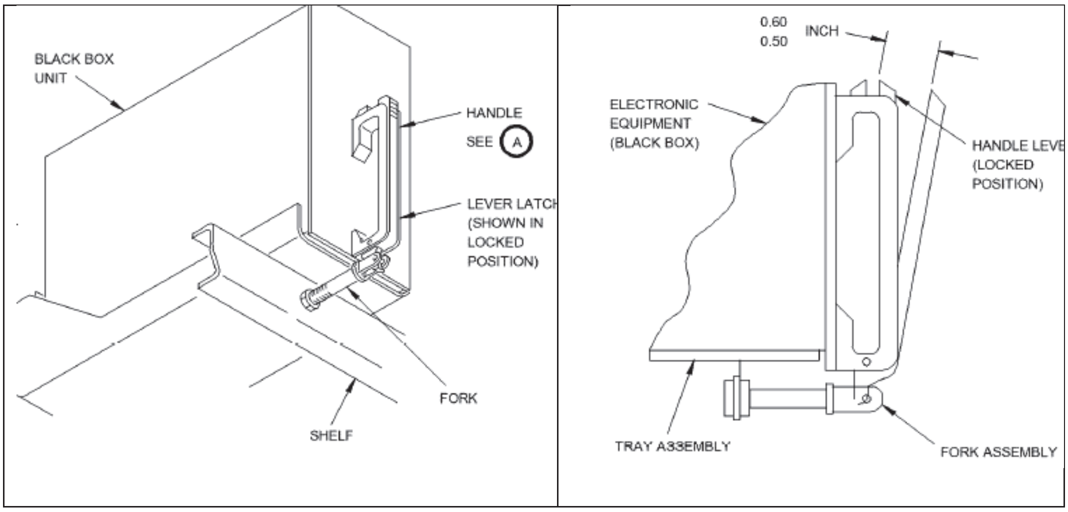

Figure 3

Racking of Generator Control Unit

Minimum Equipment List (MEL)

Purpose of the Minimum Equipment List

The EASA Acceptable Means of Compliance[4] (AMC) provides the following guidance on the purpose of the MEL:

> *'PURPOSE OF THE MEL*
>
> *The MEL is an alleviating document having the purpose to identify the minimum equipment and conditions to operate safely an aircraft having inoperative equipment. Its purpose is not, however, to encourage the operation of aircraft with inoperative equipment. It is undesirable for aircraft to be dispatched with inoperative equipment and such operations are permitted only as a result of careful analysis of each item to ensure that the acceptable level of safety, as intended in the applicable airworthiness and operational requirements is maintained. The continued operation of an aircraft in this condition should be minimised.'*

Footnote

[3] AMM, Task 20-10-07-422-011, Rack Mounted E/E Box – Installation.

[4] EASA Acceptable Means of Compliance (AMC) and Guidance Material (GM) to Annex III Organisation requirements for air operations [Part-ORO] of Commission Regulation (EU) 965/2012 on air operations. Consolidated version including Issue 2, Amendment 12, December 2017.

MEL for Boeing 737-300/400

The EASA has not issued a Master Minimum Equipment List (MMEL) for the Boeing 737-300/400, instead the operator used a MEL, approved by the CAA, which was based on the FAA Boeing 737 MMEL[5]. For an inoperative engine generator, the MMEL specified that for dispatch the aircraft required one engine generator and the APU generator, which must operate normally and be used throughout the flight.

The following statements were made in the Operation Manual regarding the use of the MEL:

- *'It is the intention that the MEL may be used to permit operations with inoperative items for a period of time until rectifications can be accomplished. These rectifications should, however, be accomplished at the earliest opportunity.*
- *It is emphasised that the existence of MEL conditions and limitations in no way absolve the Commander from ensuring that an aircraft is safe for flight, and the decision of the Commander regarding acceptance of the aircraft is final.*
- *The aircraft may depart on the flight or series of flights for the purpose of returning directly to a base where the repairs or replacements can be made/* [sic] *the aircraft may continue the flight or series of flights but shall not depart an airport where repairs or replacements can be made. This statement is intended to allow the aircraft to be flown using the most direct route, to the nearest maintenance base where arrangements for repairs or replacements can be made.*
- *Once the aircraft lands at the maintenance base, the aircraft shall not be dispatched until the defect has been rectified.'*

Rectification Interval Extension

Where a deferred defect cannot be cleared within the MEL time limits, the operator's procedures allow a one-time Rectification Interval Extension (RIE). The Operation Manual sets out the procedures for authorising an RIE and states that it should only be used in *'exceptional circumstances.'* The RIE must be approved by one of the three managers specified in the Operation Manual and must only be approved when *'…it was not reasonably practical for the repairs to be made. "Reasonably practical" means the availability of spares, time and personal.'*

Footnote

5 Boeing 737 Master Minimum Equipment List, Revision 60, Date 02/09/2018.

On 11 October 2018 an RIE was approved for the extension of MEL 24-1b on G-JMCR for Gen 1. The reason for the extension was given as:

> *'Extensive wiring checks and component replacements have been carried out to isolate the fault on generator 1 system which is tripping TRU 1 CB when selected. The fault finding so far has not managed to isolate the root cause, further trouble shooting required'*

The ADD had originally been approved when the aircraft was on scheduled maintenance at East Midlands between 5 to 8 October 2018. The aircraft then returned to the operator's main operating base at East Midlands on three further occasions before the RIE was approved when the aircraft was in Oslo. During this period, the aircraft landed at a number of other bases where troubleshooting and rectification was started but could not be completed before the aircraft was dispatched.

Aircraft examination

Following the event on 12 October 2018, an investigation into the cause of the electrical failures was carried out by the operator's maintenance staff at East Midlands who identified a fault in the left engine electrical generating system and the incorrect racking of GCU 2.

Left engine electrical generation system

The fault in the left engine electrical generation system was traced to an open phase on one of the three power feeder cables that run from Gen 1 to its generator circuit breaker. The cause of the open phase was a burnt pin on connecter C at the wing / pylon disconnect (Figure 4 and 5). The operator reported that there was no evidence of arcing between the pin and either the adjacent pins or the body of the connector; both the socket and pin appeared to be formed correctly at the crimp. Due to the extensive damage to the pin, it was not possible to establish the cause of the damage.

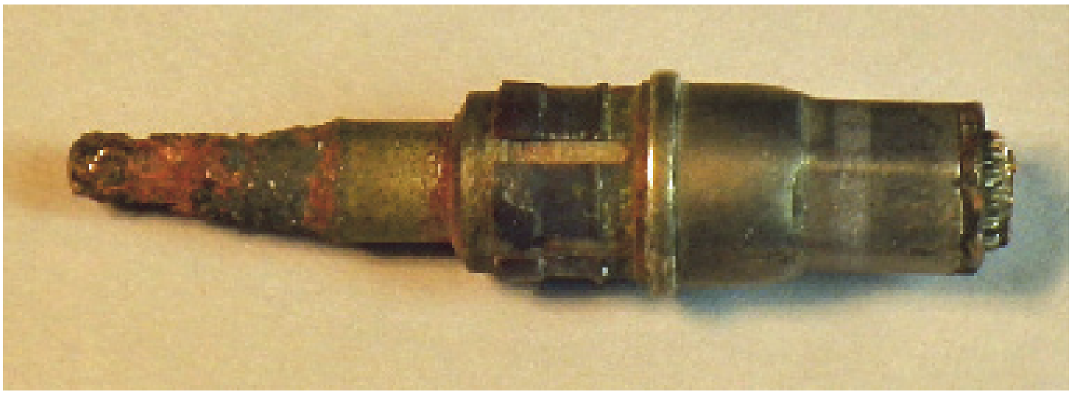

Figure 4

Burnt pin from connector C

Figure 5
Burnt pin receptacle at connector C

Comments by the aircraft manufacturer

The aircraft manufacturer advised that previous occurrences of burnt pins had usually been caused by the connector having not been correctly torqued, or because the wire spacer was missing, which created excessive load on the connector pins. When incorrectly torqued, vibration can cause the connector shell to move in relation to the receptacle connector shell. Relative motion between the connector shells would allow similar motion between the pin and socket contacts. This promotes wear and fretting corrosion that degrades the pin to socket contact interface, resulting in increased resistance and a rise in temperature. The aircraft manufacturer issued a Service Letter[6] to operators with suggested actions to ensure the best possible connection of these pins and connectors. This was a known problem.

Generator Control Unit 2

After the incident flight, GCU 2 was found to be protruding from the equipment shelf by approximately 3 cm. This would have been sufficient for the contacts at the rear of the electrical unit to disengaged with the contacts in the shelf (Figure 6). The handle lever, which was in the locked position, was found to be serviceable and the locking hook and fork intact. There was no visible damage to the electrical shelf, tray or its connectors. The electrical unit was re-racked and the right engine electrical generating system was tested and found to be serviceable.

Footnote

6 Boeing Service Letter 737-SL-24-173-A, ATA:2400-60, 1 November 2004.

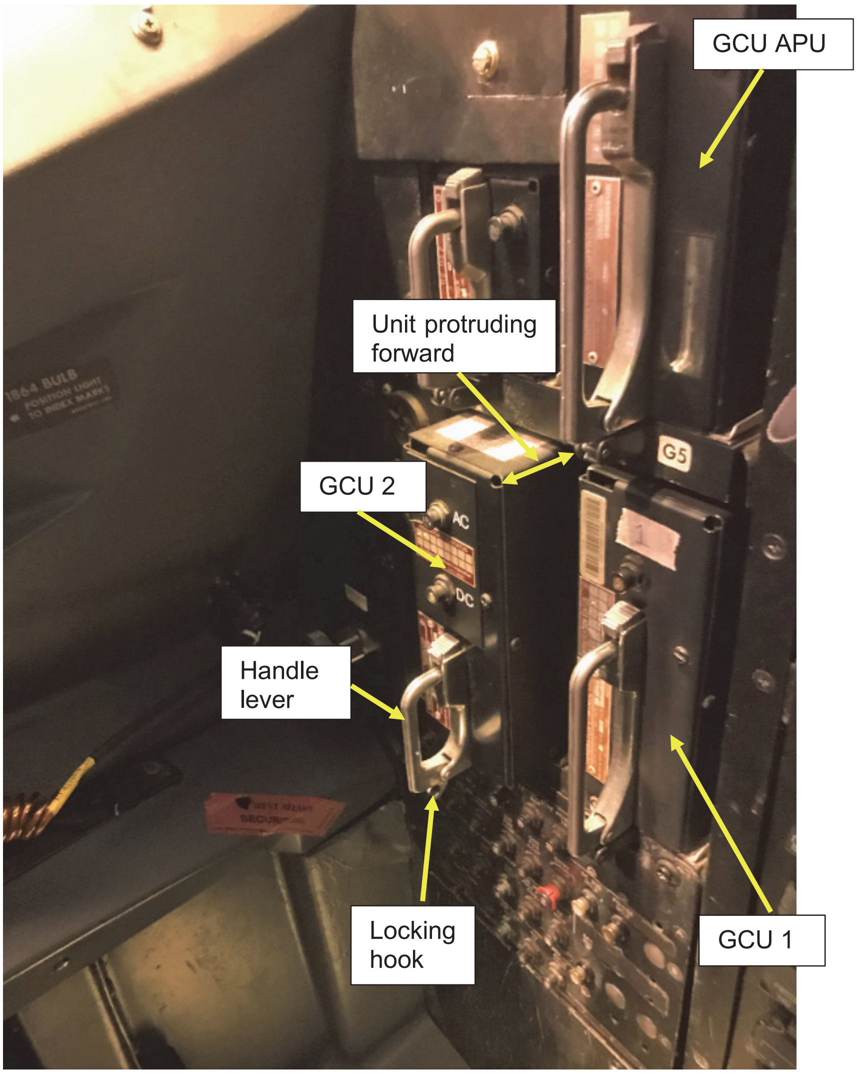

Figure 6
GCU 2 protruding forward

Comments by the aircraft manufacturer

The aircraft manufacturer advised that there had been no reports during the previous four years of electrical units having been incorrectly racked. There was also no model-wide or Boeing 737 fleet trend of units separating from the racks during flight.

Review of SRP, work sheets and Tech Log entries

As part of the investigation a time line was compiled from the entries in the company's SRP, FSR entries and the aircraft technical log. The time line revealed:

- On three occasions between 1 and 9 October 2018, GCU 2 had been transposed with either GCU 1 or the APU GCU without any documentation having been raised.

- There had been ongoing electrical problems during the 12 days prior to the incident flight when an electrical fault appeared to transfer from the APU generator system to the No 1 electrical system.
- A number of engineers during this period had recorded that the aircraft needed sufficient downtime to fully investigate the electrical faults.
- On 1 October 2018 the aircraft was allowed to operate in accordance with MEL 24-2a[7] as there was '*insufficient time'* to investigate multiple electrical failures on the ground when the APU generator was on-line.
- On 5 October 2018, an ADD in accordance with MEL 24-1b was raised for '*GEN 1 tripping TRU 1'*, while the aircraft was at the operators main engineering base at East Midlands without the engineers having determined the cause of the fault.
- On 11 October 2018, an RIE was authorised to extend the ADD for Gen 1 without the engineers having identified the cause of the electrical failures.
- On six occasions during the 12 days preceding the incident flight it appears that fault finding was either stopped or not started as there was insufficient time during the turnaround to carry out the work.
- During these 12 days the aircraft frequently passed through locations where there were sufficient maintenance resources to identify the cause of the electrical faults and clear the ADD.

Recording maintenance

The requirement for the recording of maintenance carried out on aircraft is detailed in Regulation (EU) No 1321/2014[8]. Subpart C, AMC M.A 306(a) states:

> *'AMC M.A.306(a) Aircraft technical log system*
>
> *For CAT operations, commercial specialised operations and commercial ATO operations, the aircraft technical log is a system for recording defects and malfunctions during the aircraft operation and for recording details of all maintenance carried out on an aircraft between scheduled base maintenance visits.'*

Crew experience

Both flight crew members were experienced on the aircraft type and were familiar with operating with a single inoperative engine-driven generator in accordance with the MEL. The commander had recently joined the company from another operator and was on his first week of flying having completed the company-required flight training and operational checks.

Footnote

7 MEL 24-2a allows the aircraft to operate with the APU generator system inoperative.

8 COMMISSION REGULATION (EU) No 1321/2014 of 26 November 2014 on the continuing airworthiness of aircraft and aeronautical products, parts and appliances, and on the approval of organisations and personnel involved in these tasks.

Operational procedures

Available checklists

The Boeing 737-400 uses a Quick Reference Handbook (QRH) for abnormal and emergency situations, which includes a section on aircraft electrics. None of the checklists in the QRH matched the flight deck indications directly, with the closest match being the '*Loss of all Engine Driven Generators*'. The crew did not consider this checklist as they did not believe they had lost all engine generators. Using this checklist would have involved the crew reading through the first part without completing any actions as it did not apply to their situation as the APU was already running. Eventually it would have instructed them to connect the APU generator to AC Bus 2 to power the part of the electrical system that most needed the electrical power from the APU. However, it is unclear if this would have been effective, given the inability to connect the APU onto the No 1 AC Bus at Amsterdam, and with the fault having been caused by the disconnection of GCU 2. There was no other checklist that would have provided any assistance to the crew.

Additional abnormal and emergency procedures

The operator recognises that crews can be faced with complex and challenging problems when operating an aircraft. The use of a strategy to manage the resources available to the crew and to assist them in dealing with a problem is recommended in the company Operation Manual. The strategy recommended in the manual is the decision-making tool DODAR. This mnemonic is a circular tool in that the last action is to review the actions and decisions the crew have made, thereby encouraging them to continually reassess whether their course of action is still the most valid. The letters of DODAR correspond to:

D – Diagnose (what is the problem)
O – Options (hold, divert, immediate landing etc)
D – Decide (which option)
A – Act/Assign (carry out selected option and assign tasks)
R – Review (can involve the addition of new information, and/or the ongoing result(s) of selected options)

The Operations Manual provides more information on each step of the DODAR mnemonic. Before departing on the incident flight the crew discussed what actions they might take in the event of the loss of the working engine generator. However, during this event the crew did not carry out a DODAR or use any other tool to assess the situation.

Recent maintenance

In the twelve days leading up to this serious incident there had been a number of electrical power faults on the aircraft which had resulted in engineering activity taking place at several locations across Europe. Table 1 summarises the information recorded in the aircraft technical log.

Date	Location	Entry in Tech Log	Action taken
1/10/18	Belfast	TRU[9] 1/2/3 failed on ground, multiple electrical failures.	Fault traced to APU generator. ADD and MEL raised.
2/10/18	Cologne	TRU 1 CB 'popped' during approach. Reset and failed again. Other electrical systems also failed.	Test found satis. Suspect due to electrical failure. Fault traced to suspect transfer Relay 1 (R3); relay replaced.
5/10/18	East Midlands	Clear ADD for APU electrical systems inop.	APU generator replaced. ADD and MEL cleared.
8/10/18		When Gen 1 online TRU 1 tripped.	Number 1 engine generator inop. ADD and MEL raised.
8/10/18	Aberdeen	Maintenance work to clear ADD. Number 1 generator trips TRU 1.	No 1 GCU transposed to APU position. Fault not cleared.
10/10/18	Aberdeen	Maintenance work to clear ADD. Number 1 generator trips TRU 1.	Number 1 generator replaced, fault did not clear. Open phase condition found on feeder cable, unable to isolate fault.
10/10/18	East Midlands	Normal exhaust fan power CB found tripped.	CB reset no further problems.
11/10/18	Oslo	Maintenance work to clear ADD Number 1 generator trips TRU 1.	ADD extended by a further 3 days.
11/10/18	Amsterdam	Generator 2 failed on landing with both bus off and transfer bus off lights flashing. All FO's instruments flashing and blanking.	Found FF (Feeder Fault) tripped. Reset carried out and engine tests carried out satis. Aircraft released for flight.
12/10/18	East Midlands	Serious incident occurred on flight between Amsterdam and East Midlands Airport.	

Table 1

Recent electrical faults and actions recorded in the aircraft technical log

Footnote

[9] TRU is a Transformer Rectifier Unit, which converts the AC power provided by the generators to 28V DC power.

Maintenance carried out at Amsterdam

At 0040 hrs, after landing at Amsterdam, the co-pilot contacted LMC at East Midlands while taxiing to the stand. From the LMC telephone recordings the co-pilot can be heard explaining that they had lost Gen 2 after landing. The APU generator was still running and connected, but various warning lights and instruments were "blinking". At 0054 hrs, the commander then informed LMC that he was parked on the stand and confirmed that both engine generators had failed and the voltages and frequency on the gauges all indicated zero.

At 0120 hrs, LMC contacted an EASA Part 145 organisation at Amsterdam and spoke to the senior engineer on shift and requested assistance. LMC briefed the engineer that the crew had reported that they had lost both Gen 1 and Gen 2. There was already an ADD for Gen 1. The engineer was asked to see if they could "Get the number 2 back and reset the system so that they could get the aircraft back to East Midlands". The Part 145 organisation responded to the call and recorded the work to be carried out in the billing invoice, which stated *'Both GEN'S INOP'*. No other documentation between the two organisations was raised.

At 0124 hrs, LMC contacted the commander, informed him that engineers were on their way and asked for a full description of the electrical problems on the aircraft to record on their system (FSR). The commander gave a very detailed brief during which clarification as to what the crew had experienced was sought by LMC. LMC commented that there was a serious electrical problem on the aircraft and they had been unable to identify the root cause. He advised the commander to wait and see what the engineers at Amsterdam found.

A licensed engineer (B1) with a type rating for the Boeing 737-300/400 was tasked to attend the aircraft and as the shift was relatively quiet was accompanied by the senior engineer. On arriving at the aircraft, the engineer noted that the Ground Power Unit (GPU) was connected and the APU was not running. In this configuration the GPU should have powered both Gen Bus 1 and 2. However, the indications showed that only Gen Bus 1 was powered, which was not what the engineer expected to see. Following a brief from the commander, the engineer believed that Gen 2 disconnected from Gen Bus 2 in flight; however, this was not the case. He also noted from his conversation with the commander and from reading the technical log that there was an ADD for Gen 1. However, the technical log entry made by the commander, which said '*Gen 2 failed on landing, with both bus off & transfer bus off lights flashing, also all FO's instruments flashing and blanking*', confused the engineer who could not understand why both generator busses were OFF when the APU generator would still have been on-line. The engineer was not aware that the GEN 1 OFF Bus light on the Bus switching panel had been removed as part of the MEL and, therefore, could not have illuminated during the flight.

The engineer's first action was to visually check the position of the 'AC' and 'DC' circuit breakers on the front of GCU 2. Both circuit breakers appeared to be fully in. He did not touch the GCU and was also not aware of it protruding forward out of the rack. He then checked the fault lights on Panel M238 and found that for Gen 2, the 'FF' lamp was illuminated; the lamps for 'MT', 'HV' and 'LV' were all extinguished.

Based on the briefing from the commander and the illuminated lamp 'FF', the engineer followed the trouble shooting chart for '*The feeder fault light on the annunciator panel comes on*'. As part of this action the engineer opened the cowling on the right engine and checked the drive on the CSDU (which had not disconnected) and the feeder cables from the generator to the Differential Protection Current Transfer, which visually appeared to be normal.

Once the cowling had been closed, the commander, at the request of the engineer, started the right engine using the APU generator to power Gen Bus 1. When selected, Gen 2 would not come on-line. The engineer then cleared the 'FF' code on Panel M238 by pressing the ERASE button on the panel. When selected, Gen 2 connected to Gen Bus 2. With Gen Bus 1 powered by the APU, Gen 2 was cycled several times and it connected to Gen Bus 2 every time.

At 0155 hrs, the commander contacted LMC and told them the problem had been fixed and then passed the telephone to the engineer. The engineer told LMC that there had been a "frequency fault" which had been cleared by resetting the circuit breaker. The engineer mentioned that from the technical log there seemed to have been a number of electrical problems on the aircraft and LMC responded that they were going to conduct a further investigation over the weekend. The engineer cleared the entry in the aircraft technical log and the commander accepted the aircraft for flight.

The senior and licensed engineers both said that it was not a particularly busy night and that there was no pressure on them to complete the work and return the aircraft to service. They did not have access to the operator's on-line portal which provided a technical history of the aircraft, but instead relied on the brief from the commander and the limited information in the technical log. The task in clearing the fault, from initial callout to clearing the entry in the technical log, took approximately 35 minutes.

The AAIB investigation could identify no evidence to show that the aircraft would have been grounded when it reached East Midlands for further investigation work on the electrical systems to be carried out. Instead, the same crew had been scheduled, after a short stop at East Midlands, to continue their flight in this aircraft to Aberdeen.

Safety Management System

Requirements

Both ICAO[10] and EASA[11] require operators to have a Safety Management System (SMS) in order to continuously manage the safety risks associated with their activities and responsibilities. The safety risk management system should describe the operating system and have policies and procedures to identify the hazards, and assess and control the risks.

Footnote

[10] ICAO Doc 9859 AN/474, Safety Management Manual (SMM).
[11] Commission Regulation (EU) No 965/2012. as subsequently amended.

Operator's process

The Operator's SMS is detailed in its Management System Manual that integrates the functions of safety and compliance monitoring and management. The following posts are responsible to the Accountable Manager for discharging their SMS responsibilities:

- The Flight Operations Manager is responsible for the overall safety of the Flight Operations.
- The Ground Operations Manager is responsible for the Management of Ground Operations on a day to day basis.
- The Continuing Airworthiness Manager is responsible to the Accountable Manager for Continuing Airworthiness activities.

Analysis

Cause of the electrical failures

The electrical failures that occurred during the landing at Amsterdam and on the subsequent flight to East Midlands were caused by GCU 2 moving forward in its rack far enough to cause the electrical connectors to disconnect. The flickering lights and screens indicate that initially there was a partial connection that was intermittent, but on landing at East Midlands the GCU appears to have moved forward sufficiently for the connector to fully disconnect. This would have resulted in the loss of: Gen 2; Gen Bus 2; Transfer Bus 2; 115V AC Electronic Bus 2; 28V DC Bus 2; and 28V DC Electronic Bus 2. Electrical System 1 would still have been powered by the APU generator through Gen Bus 1.

The Boeing 737-400 is not designed to operate with the GCU disconnected. While there was no record in the aircraft technical log or worksheets for the previous 12 days of GCU 2 having been disturbed, messages on the company's FSR stated that it had been disconnected on three occasions during this period as part of the fault finding to clear the ADD on the left engine generator.

Details of the effects of the GCU disconnection on the aircraft's electrical system are contained in Appendix 1 to this report.

Management structure

Since November 2017 the operator had experienced a number of significant changes. There had been an increase of approximately 30% in the number of aircraft and staff with the operator's main operating base and LMC moving from Coventry Airport to East Midlands Airport. The administration of the AOC and Part M responsibilities also moved from Coventry Airport, to a nearby business park. The operator's own audit recognised the need to change the management structure of LMC and improve the management of defects and the competency of the staff within the LMC. This serious incident occurred during this transition period.

Flight crew performance

At no stage during the event did the flight crew consult the QRH or attempt to analyse the fault. They did not use either the operator's suggested decision-making tool DODAR nor any other tool. Given the good weather conditions, the point in the flight when the failure occurred, and the availability of a long runway at East Midlands, the crew were able land the aircraft safely with few issues. Had the crew performed some kind of analysis and discussed options for a safe landing, it is likely that they would have decided that landing at East Midlands was still the safest option.

If the aircraft had been in cloud, with poor weather conditions on the ground, the crew would have faced a challenging recovery with little automation available and with the co-pilot unable to monitor the flight path of the aircraft. The use of a suitable decision-making tool, such as DODAR, would have aided the crew in analysing the problem and agreeing a suitable solution. It would also have prompted them to consider what systems may have been inoperative, and its effect on the approach and aircraft's landing performance. Although the time available to the crew was only around 15 minutes, this was long enough for such an analysis to be performed without delaying the approach and landing.

Use of the MEL and RIEs

The operator did not appear to use the MEL in the spirit of EASA's Acceptable Means of Compliance or its own procedures. Rather than using the MEL to allow the aircraft to return to its main operating base where the faults could be rectified, it appears to have been used to enable the aircraft to meet operational commitments. Fault finding, and rectification was frequently stopped before the root cause had been identified and on a number of occasions the aircraft was dispatched from a location where the work could have been carried out.

The burnt pins on the feeder cable was a known fault. On 10 October 2018, an engineer correctly identified that there was a FF on Gen 1 and inspected the connector between the engine and pylon but ran out of time to check the connector between the pylon and wing where the burnt pin was located.

The RIE for the defect on Gen 1 should only have been granted in exceptional circumstances. However, while resources were available to identify and fix the fault within the specified time, the RIE was approved to enable the operator to meet operational commitments.

There also seemed to be confusion with operations and engineering staff within the LMC and the Part M organisation as to what constituted a main operating base. It was commonly believed that a number of locations across their operating network that had Part 145 organisations could be considered as a main operating base and that it was acceptable for aircraft to be dispatched from East Midlands with an ADD operating in accordance with the limitations in the MEL. This was, however, contrary to the operator's Operation Manual.

The confusion as to what constituted a main operating base and the routine deviation from the operator's procedures on the use of the MEL and RIE might have partly been due to the operator's policy and procedures not being suitable for its routine operations. Therefore, the following Safety Recommendation is made:

Safety Recommendation 2019-004

It is recommended that West Atlantic UK revises its policy and procedures for approving and clearing Minimum Equipment List entries and Rectification Interval Extensions to ensure that it conforms with the guidance contained within the European Union Aviation Safety Agency Acceptable Means of Compliance.

Management of defects

The operator recognised that the management of defects and rectification across their fleet was challenging due to the nature of their operations. The aircraft were rarely in the same place on consecutive days and there were frequently changes to the flying programme, which made the provision of spares, specialist engineers and equipment difficult. The operator's staff were also conscious of the tight turnaround times that their customers expected and whilst there was no evidence of external pressure having been applied to any individuals, there may have been an element of self pressure to ensure that aircraft were not delayed. Fault finding was frequently stopped part way through and on three separate occasions the GCU were swapped without the aircraft documentation having been completed in accordance with Commission Regulation (EU) No 1321/2014, (continuing airworthiness). The following Safety Recommendation is made:

Safety Recommendation 2019-005

It is recommended that West Atlantic UK ensures that all work undertaken on its aircraft is documented in accordance with the requirements of Regulation (EU) No 1321/2014 (regarding continuing airworthiness).

The management of defects was primarily carried out by staff in the LMC. These individuals may be required to manage a number of issues on separate aircraft during their shift. Their main aim is to ensure that the company meets its operational commitments during their period of duty. The main oversight was undertaken during the 0600 hrs morning conference which involved representatives from LMC and the Part M organisation using the updates provided on the operator's messaging system. Despite numerous entries on FSR highlighting concerns with the electrical system on G-JMCR, and the difficulty in completing the fault finding during the tight turnaround times, there was no evidence of a plan to ensure that the aircraft was given sufficient downtime to rectify the faults and clear the ADD. Instead, the issue drifted on with an RIE approval and a number of engineers at different locations repeating similar fault-finding tasks until eventually the GCU was incorrectly secured and disconnected in flight.

The operator has addressed the situation by establishing the post of Defect Controller who reports through the Part M organisation. However, this individual is not available outside normal office hours or during periods of holiday or sickness. Moreover, the morning conference calls only take place during the normal working week which means that frequently only the operations supervisor and the LMC staff are in a position to undertake a dynamic risk assessment of the ongoing airworthiness of individual aircraft. While these individuals have the authority to prevent an aircraft flying if they believe it is unsafe to do so, it might not be apparent to them that this dynamic oversight is a key part of their job. The following Safety Recommendation is made:

Safety Recommendation 2019-006

It is recommended that West Atlantic UK revises its policy and procedures to ensure effective management of defects, and the undertaking of dynamic risk assessments of the airworthiness of aircraft during all hours of operation.

Communicating with other Part 145 organisations

The electrical fault that occurred during the landing at Amsterdam was unusual. Lights and screens that can only be on or off were flashing which indicated that there was an intermittent fault within the No 2 electrical system that eventually caused the circuit breaker for GCU 2 to trip. The Part 145 engineers did not have access to the operators FSR and would not have known the history of the electrical problems on the aircraft, which LMC described to the commander as serious. While the commander gave a detailed explanation to LMC as to the problems he had experienced, this was not relayed to the engineer who was tasked with rectifying the problem with Gen 2 and resetting the system so that the aircraft could return to East Midlands. No written tasking document, recent history of the aircraft or the concerns from LMC that there was a serious electrical problem on the aircraft were provided to the engineer. The engineer reset the system as requested and reported back to LMC who did not ask him to undertake any further work. The total time from the engineer being tasked to travelling to the aircraft and completing the work was 35 minutes.

In completing the trouble shooting as laid out in the Maintenance Manual, the engineer had satisfactorily completed the task he was given, which was to investigate why the two serviceable generators were inoperative. But the circuit breaker that was found to have tripped could not have caused the intermittent electrical supply to the flight deck instruments. Significantly, no one appeared to address the potential increase in risk to the safe operation of the aircraft should the fault reoccur in flight while operating with one generator already inoperative in accordance with MEL 21-1b.

The commander initially felt uneasy at the fault being cleared but was reassured when the engineer discussed what he had done with LMC: the engineer felt that his conversation with LMC was more to do with when the aircraft could be returned to service. In turn, the LMC was reassured by the commander, who was new to the company, and the engineer that the aircraft was now serviceable. However, the engineer in Amsterdam did not have knowledge of the ongoing electrical problems on the aircraft and none of the three parties discussed the impact of the fault on Gen Bus 2 reoccurring during the next flight. In summary, none of the three individuals involved had the full picture on the condition of the aircraft and a risk assessment was not carried out to determine if the aircraft was in a safe condition to continue flying with one generator inoperative. The following Safety Recommendation is made:

Safety Recommendation 2019-007

It is recommended that West Atlantic UK revises its policy and procedures for the tasking of maintenance activities by Line Maintenance Control and the sharing of relevant aircraft technical history to ensure that maintenance organisations undertaking work have access to all appropriate information.

Safety management system

This investigation identified safety issues across a number of areas that had not been identified or addressed by the Operator's SMS. Therefore, the following Safety Recommendations are made:

Safety Recommendation 2019-008

It is recommended that West Atlantic UK revises its Safety Management System to meet the requirements of the scale and nature of their operation.

Safety Recommendation 2019-009

It is recommended that the Civil Aviation Authority assess West Atlantic UK's Safety Management System to ensure it meets the requirements of the scale and nature of their operation.

Conclusion

This serious incident was caused by the incorrect racking of GCU 2 which moved forward in flight initially causing an intermittent and then total disconnection of the electrical connector. The aircraft was not designed to operate with the GCU disconnected and the crew were presented with an unusual situation that was not covered in the QRH.

The activities surrounding the management of the faults on G-JMCR during the previous 12 days, and the actions of the crew in handling the emergency, indicates a weakness in the operator's policies and procedures for the management of risk. Engineers were not always given sufficient time to investigate the faults, with the result that fault finding was often repeated and not finished. Work at a number of locations was not recorded as having been carried out in the aircraft documentation. The aircraft was dispatched from its main operation base with an ADD and flew through a number of locations where it could have been cleared, which was contrary to the procedures in the Operation Manual.

Communication between LMC, the commander and the Part 145 organisation at Amsterdam was ineffective in highlighting the underling technical problems on the aircraft. The engineer was unaware of the full history of the faults and the concerns that LMC conveyed to the commander that there was a "serious electrical fault on the aircraft". The engineer was tasked with resetting the generators and spent less than 30 minutes at the aircraft. Despite the ongoing concerns with the electrical systems previously raised by a number of engineers and crews, and the unusual set of failures that occurred during the landing at Amsterdam, LMC did not carry out any form of risk assessment or ensure a deeper investigation was carried out before the aircraft departed Amsterdam. While the commander had the ultimate decision on accepting the aircraft, he was new to the company and may have relied on the advice of the engineers without being aware that the engineer had only been tasked with resetting the generators.

The operator had previously identified that there was a need to restructure LMC, introduce the post of Defect Controller and provide staff with further training to improve their competency.

Safety actions proposed by the operator

As a result of this serious incident, and the findings of the AAIB, the operator has stated that they will take the following safety actions:

- Redefine the criteria of a maintenance base with each aircraft allocated to a specific maintenance base dependent on the route flown.
- All ADDs will be monitored daily and best endeavours made to rectify them within 48 hours. Where this time limit is not achieved an occurrence report will be raised to enable an investigation to be carried out to establish why this was not possible.
- A Safety Report will be raised via the SMS for all RIE applications.
- Monitor in real-time the management of ADD and RIE applications using a number of Performance Indicators over a 12-month rolling period.
- LMC will be informed of all intended deferred defects before actual deferral.
- Prior to deferral of a defect, a risk assessment based on the source of the fault and subsequent impact on the aircraft systems and operational limitations will be carried out by an engineer in consultation with the crew. LMC will provide historical defect information relevant to the unserviceable system in question and knowledge of the aircraft's historical airworthiness generally.
- An additional status header of 'Risk Assessment' has been added to the FSR. A summary of the risk assessment will be documented in the FSR against the deferred defect highlighting significant risks that are associated with the aircraft's airworthiness status.
- A review of persons authorised to ground a serviceable aircraft without reason and with good reason following a risk assessment has been carried out.

- Procedural deficiencies were identified in the following processes. A compliance review of these areas had been planned for completion by 31 July 2019 with corrective and preventative actions identified implemented by 30 Sept 2019.

    - Risk management of deferred defects.
    - Rectification management of deferred defects.
    - Interface between LMC and remote Part 145 organisations.
    - Standardisation of policy across all departments concerning deferred defect control.

Safety Recommendations

The following Safety Recommendations are made in this report:

Safety Recommendation 2019-004. It is recommended that West Atlantic UK revises its policy and procedures for approving and clearing Minimum Equipment List entries and Rectification Interval Extensions to ensure that it conforms with the guidance contained within the European Union Aviation Safety Agency Acceptable Means of Compliance.

Safety Recommendation 2019-005. It is recommended that West Atlantic UK ensures that all work undertaken on its aircraft is documented in accordance with the requirements of Regulation (EU) No 1321/2014 (regarding continuing airworthiness).

Safety Recommendation 2019-006. It is recommended that West Atlantic UK revises its policy and procedures to ensure effective management of defects, and the undertaking of dynamic risk assessments of the airworthiness of aircraft during all hours of operation.

Safety Recommendation 2019-007. It is recommended that West Atlantic UK revises its policy and procedures for the tasking of maintenance activities by Line Maintenance Control and the sharing of relevant aircraft technical history to ensure that maintenance organisations undertaking work have access to all appropriate information.

Safety Recommendation 2019-008. It is recommended that West Atlantic UK revises its Safety Management System to meet the requirements of the scale and nature of their operation.

Safety Recommendation 2019-009. It is recommended that the Civil Aviation Authority assess West Atlantic UK's Safety Management System to ensure it meets the requirements of the scale and nature of their operation.

APPENDIX 1

Transfer of electrical power

With GCU 2 correctly racked

Each generator Bus provides power to a Transfer Bus through the NORMAL position of the Transfer Relays (R3 /R4). If one generator losses power, and provided the Bus Transfer switch is at AUTO, the remaining generator will automatically power the other generator's Transfer Bus. During the accident flight, Gen Bus 1 was powered by the APU and Gen Bus 2 by the generator on the right (2) engine. This situation is shown at Figure 7.

The loss of power from Gen 2 would normally result in circuit breaker (CB2) opening causing the coil in the Transfer Control Relay R350 to deenergise. This would provide a path for the 28V DC power from the DC Bus through GCU 2 to energise the Alternative coil in Transfer Relay 2. At the same time the Normal coil in Transfer Relay 2 would deenergised and the Bus Off light on the overhead panel would illuminate.

With GCU 2 disconnected

The situation where the electrical connectors at the back of the GCU 2 electrical unit become disconnect in flight is shown at Figure 8. Circuit Breaker 2 (CB2) would have tripped and the loss of control from GCU 2 would have caused generator 2 to stop producing power. The electrical path between the 28V DC supply to Transfer Control Relay (R350) would be broken and the relay would deenergise. The path from Transfer Control Relay (R350) to both the Normal and Alternative coil in Transfer Relay 2 (R4) would also be broken and both relays would deenergise. With no electrical power at Relay 350, the Transfer Bus 2 light in the cockpit would illuminate. Once CB2 had tripped, reconnection of the electrical connecter to GCU 2 would have energised the Alternative coil in Transfer Relay 2 (R4) enabling Transfer Bus 2 to be powered by Gen Bus 1.

Published 5 September 2019.

BULLETIN CORRECTION

In the last paragraph of the Synopsis of this report it was stated that six Safety Recommendations are made to the operator regarding its safety management system and one to the Civil Aviation Authority.

This is incorrect it should have read **five** Safety Recommendations are made to the operator regarding its safety management system and one to the Civil Aviation Authority.

The online version of the report was amended on 10 October 2019.

Appendix 1 cont

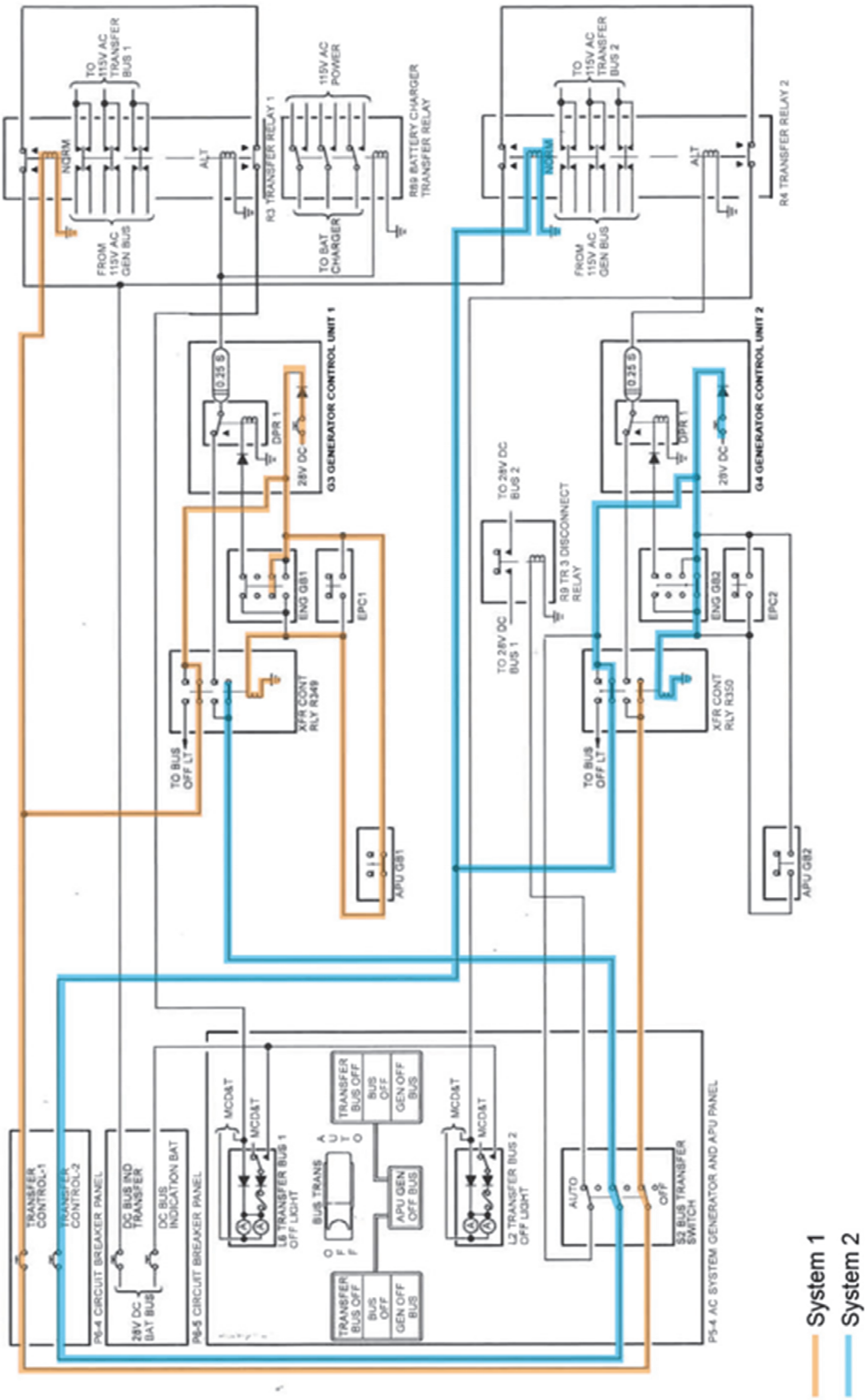

Figure 7

Routing for electrical power at start of flight

Appendix 1 cont

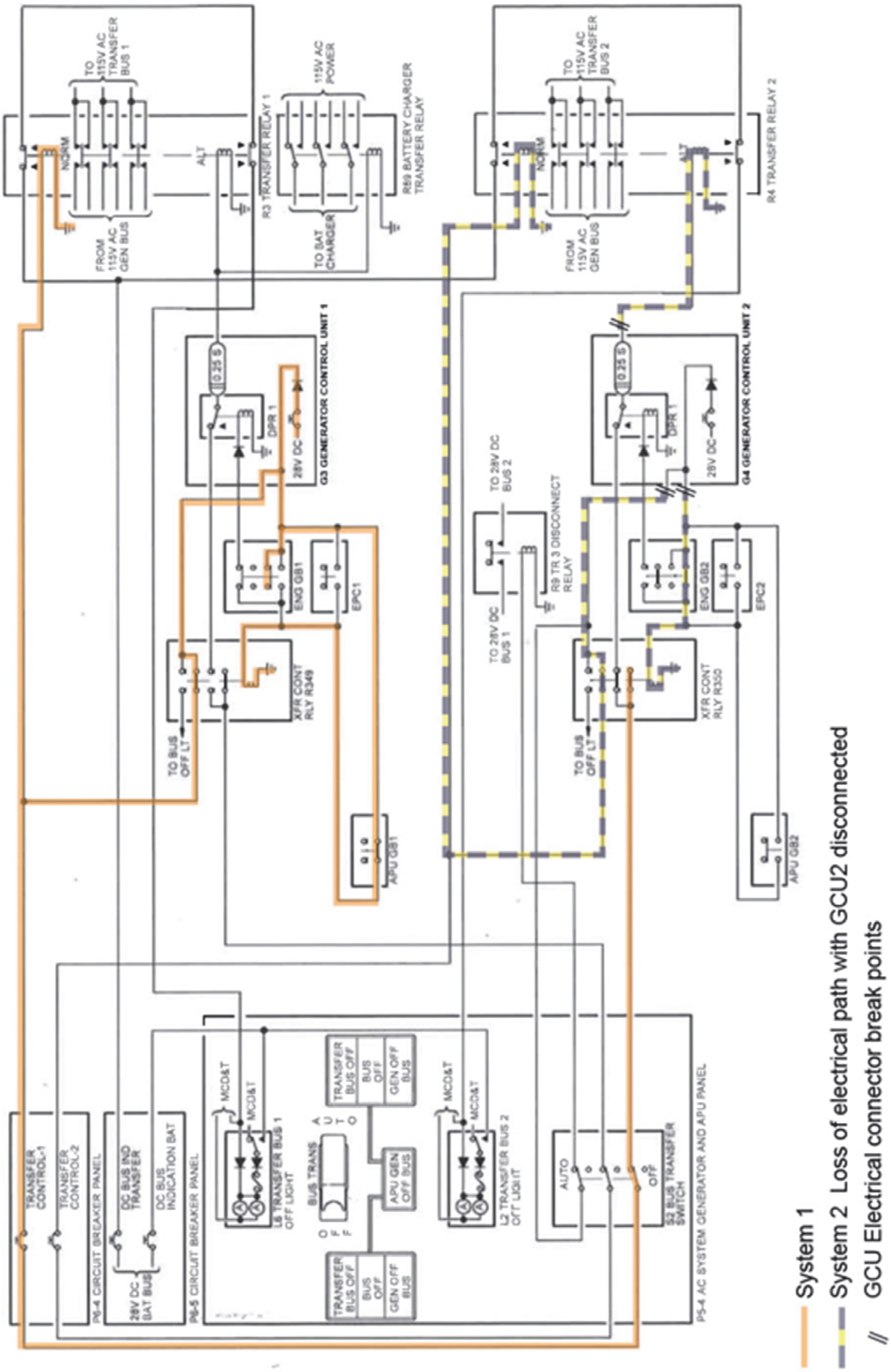

Figure 8

Routing for electrical pwer after disconnection of GCU2