SERIOUS INCIDENT

Aircraft Type and Registration:	Boeing 737-4Q8, G-JMCR
No & Type of Engines:	2 CFM CFM56-3C1 turbofan engines
Year of Manufacture:	1992 (Serial no: 25372)
Date & Time (UTC):	4 June 2019 at 1846 hrs
Location:	Brussels National Airport, Belgium
Type of Flight:	Commercial Air Transport (Cargo)
Persons on Board:	Crew - 2 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	None
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	34 Years
Commander's Flying Experience:	2,525 hours (of which 2,325 were on type) Last 90 days - 83 hours Last 28 days - 7 hours
Information Source:	AAIB Field Investigation

Introduction

Annex 13 to the Convention on International Civil Aviation places a responsibility on the State of Occurrence, in this case Belgium as represented by the Air Accident Investigation Unit (AAIU), to commence an investigation. However, the State of Occurrence may, by mutual agreement, delegate the investigation to another State. On 5 June 2019, the AAIU delegated responsibility for this investigation to the State of Registration, as represented by the AAIB.

Synopsis

While descending to land at Brussels National Airport, a partial electrical failure occurred resulting in the loss of a number of systems including the electronic and analogue flight instruments on the left side of the cockpit. The pilot declared a MAYDAY and aware that a thunderstorm was approaching the airfield, assessed that the weather reported by Air Traffic Control (ATC) would allow him to continue and land at Brussels. However, visual references were lost at a late stage of the approach when the aircraft entered a heavy rain shower. A go-around was initiated during which the pilots estimated the amount of thrust required; the aircraft initially appeared to be slow to accelerate and establish a positive rate of climb. The aircraft entered an orbit and subsequently landed successfully from a second approach.

The electrical failure was caused by a fault in the transfer relay which resulted in the loss of power to a number of electrical buses. The aircraft documentation was unclear as to

which aircraft in the fleet were configured to enable the cockpit instruments to be powered from a standby electrical source; this may have affected the pilots understanding of the failure. Safety action has been taken by the operator to provide clarity in the aircraft documentation.

History of the flight

The aircraft was en route from Oslo Gardermoen Airport, Norway to Brussels National Airport, Belgium with the commander, a company line training captain, in the right seat as the PM and the co-pilot, who was completing his command upgrade line training, in the left seat as PF.

The weather was forecast to be thundery in the Brussels area and the pilots heard ATC directing other aircraft around active thunderstorms as they approached the airport. They could also see thunderstorm activity in the vicinity of the airfield but the area towards the south-east was clear. After listening to ATIS, they configured the aircraft for an ILS approach with an automated landing to Runway 25R. As part of the approach brief, which was carried out prior to the start of the descent, they set the speed bugs for a flap 40° landing and discussed the possible threats they might encounter.

At 1846 hrs, during the descent, the pilots heard a noise which they described as a "large electrical clunk". This was accompanied by the loss of the primary EFIS[1] screens on the left side of the cockpit and the disconnection of the autopilot and autothrottle. The commander immediately took control as PF and flew the remainder of the flight manually, with the co-pilot assuming the role of PM. ATC advised that there were no secondary radar returns from the aircraft and at 1848 hrs, while descending through 8,400 ft, the PM requested priority for approach to Runway 25R and declared a PAN.

The pilots established that, in addition to the loss of the EFIS screens, both control display units for the Flight Management Computer (FMC) were inoperative and several caution and advisory warnings had illuminated. These included: the No 1 aft fuel pump LOW PRESSURE; the pressurisation system AUTOFAIL and STANDBY; the left side pitot static system; L ALPHA VANE and YAW DAMPER. The back lighting for the overhead panel was not working and no cautions or advisories had illuminated for the electrical systems.

Given the expected weather around the airport, the pilots discussed the threats in relation to flying a manual ILS approach. As the flight could be completed in VMC, the standby instruments and the PF's EFIS were serviceable, there was no degradation in the other aircraft systems and they had already briefed and prepared the aircraft for landing, they decided to continue and land at Brussels.

At 1850 hrs, the PM advised ATC that the aircraft had suffered a "severe electrical issue" and requested immediate vectors for an ILS approach to Runway 25R. The PM upgraded the PAN to a MAYDAY and the pilots carried out the landing checks. ATC advised that the

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[1] Electronic Flight Instrument System consists of two screens, Electronic Attitude Director Indicator (EADI) and the Electronic Horizontal Situation Indicator (EHSI).

aircraft was at 17 nm, cleared it onto base leg and to descend to an altitude of 2,000 ft. They subsequently advised the pilots that the aircraft was 6 nm from the threshold; the PM responded that since they were at an altitude of 3,500 ft, they would need more than 6 nm. ATC instructed them to "fly through the localiser". However, as they approached the extended centre line, the PM reported that they were visual with the runway and ATC gave permission to commence a visual approach. The pilots reported they selected 40° flap, intercepted the glideslope from above and were stable at between 1,000 and 1,500 ft. ATC cleared the aircraft to land at 1855 hrs and advised that the surface wind was 5-8 kt from 230º. At around this time the PF noticed that the Enhanced Ground Proximity Warning System (EGPWS) was not working.

The pilots reported that when they commenced the approach, they saw "a big cell[2] at the end of the runway curving round to the north. It was fairly active with a wall of water and lightning strikes every 20 seconds", but the weather was clear to the south of the airfield. Consequently, the PM requested an immediate left turn in the event of a missed approach. However, at about 300 ft agl and 1 nm, the pilots lost visual references as they entered a heavy rain shower so the PF executed a go-around by estimating the amount of thrust required. The pilots reported that they momentarily felt a "sinking in the air" and the aircraft was initially slow to accelerate and establish a positive rate of climb before achieving a climb rate of 2,500 to 3,000 fpm. The PF flew the missed approach and orbited visually to the south-east. At this point the PM selected the transponder to ATC 2, which restored the secondary radar return enabling ATC to confirm the position and altitude of the aircraft.

While orbiting the pilots reviewed the effect of the electrical failure and associated indication. The PM noted that the Transfer Bus No 1 Normal circuit breaker (C819) was open and identified the most appropriate procedure from the Quick Reference Handbook (QRH) was '*TRANSFER BUS OFF*'. This procedure had a pre-condition that the TRANSFER BUS OFF caution should be illuminated; however, as it had not illuminated the pilots decided not to use this procedure. They also decided not to reset the circuit breaker as the aircraft had sufficient systems functioning to enable a safe landing.

They considered a diversion but decided against it since the aircraft was in a stable state, there was no urgency, and there was enough fuel onboard to hold until the weather at Brussels improved. The PM advised ATC of the situation, that they had "lost a lot of systems" and were reliant upon basic navigation only.

Once ATC reported that the weather had cleared, the pilots requested a visual approach. The aircraft landed at 1922 hrs and on touchdown the left intercom, VHF 1 radio, and both engine N_2 and EGT gauges stopped working.

Footnote

2 A storm cell is an air mass that contains up and down drafts in convective loops and is the smallest unit of a storm-producing system. A thunderstorm can contain a number of storm cells.

Commanders experience of manual flying and conducting a go-around

The commander informed the AAIB that as part of his training role he routinely manually flew the aircraft and in the previous year had flown seven go-arounds, of which three had been in the last three months and the most recent the day prior to the event flight.

Recorded information

ATC recordings and primary radar were available for the duration of the flight. Secondary radar returns were available prior to the event and after transponder ATC 2 was selected following the go-around. Data recording on the FDR and CVR stopped when power was lost as a result of the failure of the electrical failure.

The position of the aircraft when the electrical failure occurred and where a number of the radio calls between the crew and ATC took place are plotted at Figure 1. It was approximately five minutes between ATC informing the crew that they had "no read out from Mode C" to the aircraft intercepting the localiser. During this period the pilots made or responded to numerous radio calls, while being vectored and assessing the effect of the electrical failure on the aircraft systems.

As the aircraft descended through 8,400 ft the PM informed ATC that they had "technical problems and will advise of intentions" and requested priority for Runway 25R. Shortly afterwards the aircraft was cleared to descend to 2,000 ft with a heading that would give a distance to touchdown of 22 nm. The PM requested an additional 10 nm and was given a new heading. After a further 40 seconds the PF advised ATC that they had a severe electrical issue, were levelling at 5,000 ft and requested immediate vectors for the ILS on Runway 25R. ATC acknowledged the call, advised that the distance to touchdown was 17 nm and asked if they were ready for the base turn, which the PF "affirmed". Less than twenty seconds later the PF advised they had a partial electrical failure. ATC asked for clarification which the PM provided. The PF then declared a MAYDAY and ATC reported the distance to touchdown as "about one two miles". The PF reported the altitude as 4,300 ft. One minute later ATC report the distance as 6 nm to touchdown; the primary radar showed the aircraft to be at approximately 10 nm.

The aircraft appeared to level as the PM responded to the incorrectly reported distance by saying that they needed more than 6 nm and were at 3,500 ft. ATC cleared the aircraft to fly through the localiser and as it approached the extended centre line the PM reported they were visual with the airfield and requested, and were given, clearance for a visual approach for Runway 25R. The aircraft was approximately 9 nm from the threshold with a reported height of 3,500 ft, which placed it approximately 700 ft above the glideslope.

Aircraft information

G-JMCR is a Boeing 737-4Q8 aircraft which was converted to a freighter in 2013. At the start of the flight the aircraft had no recorded deferred defects.

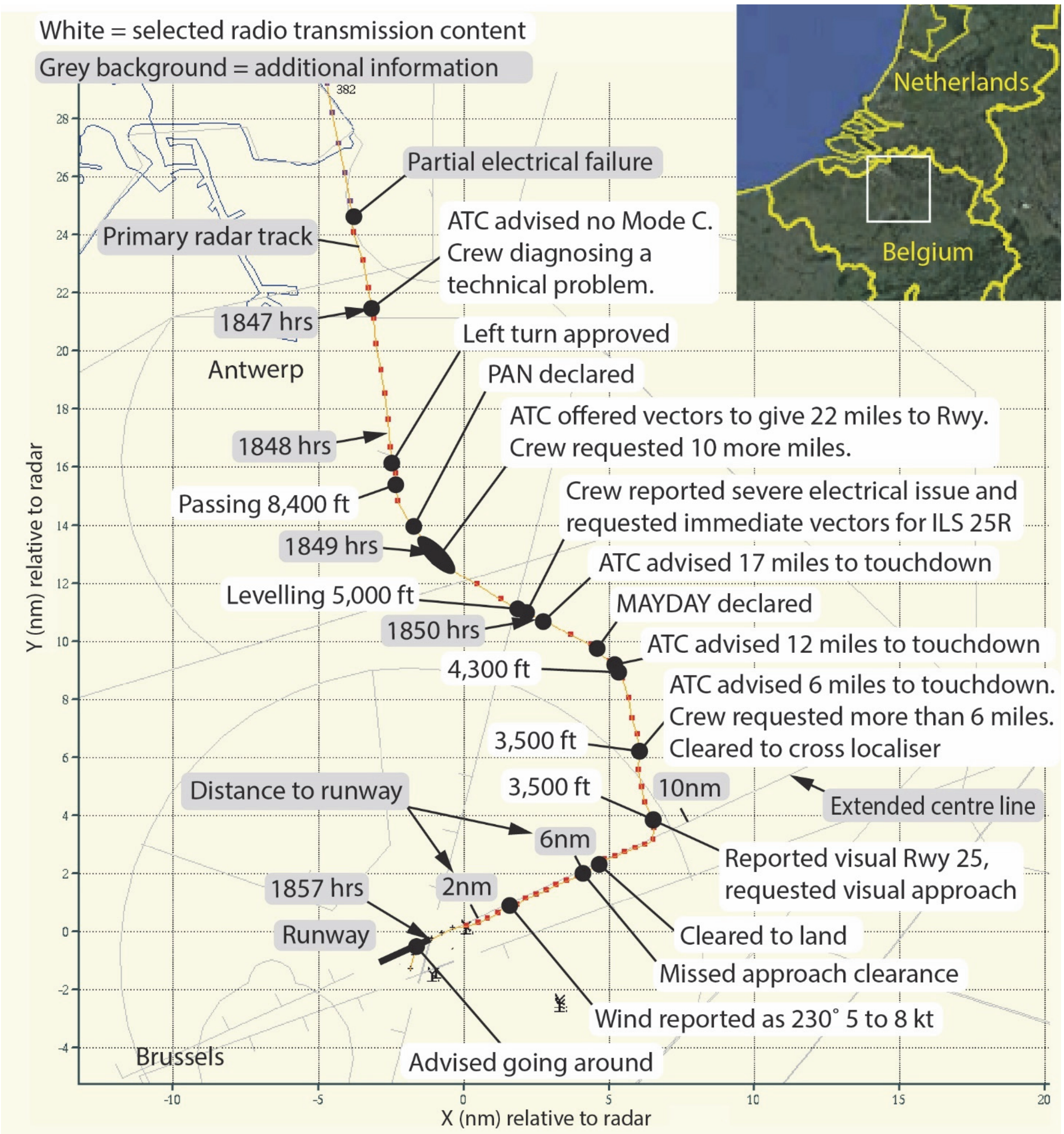

Figure 1

Primary radar track and timing of some radio calls

Systems description

Electrical power systems

On G-JMCR, AC electrical power is provided by one generator fitted to each engine and one generator connected to the APU. The normal inflight configuration is for each of the engine-driven generators to power its associated 115v AC generator buses (GEN BUS 1 or 2). If one engine generator is inoperative, the APU generator may be used to power the inoperative bus. One generator (engine-driven or APU) can provide sufficient power for all essential flight systems. A partial schematic of the electrical power system is shown in Figure 2.

Power transfer from the generation bus to the transfer (distribution) buses is achieved through two transfer relays, 1 and 2, which contain two sets of primary and two sets of auxiliary contacts. The transfer bus control switch is normally set to AUTO and should a generator bus failure occur, the 28v AC Generator Control Units (GCU) will automatically switch the relay to supply the affected transfer bus from an operational generator bus. When the transfer bus switch is moved to OFF, a caption will illuminate to indicate that the bus is isolated from the generator. Following a loss of power from a generator bus, the GCU will illuminate the OFF caption.

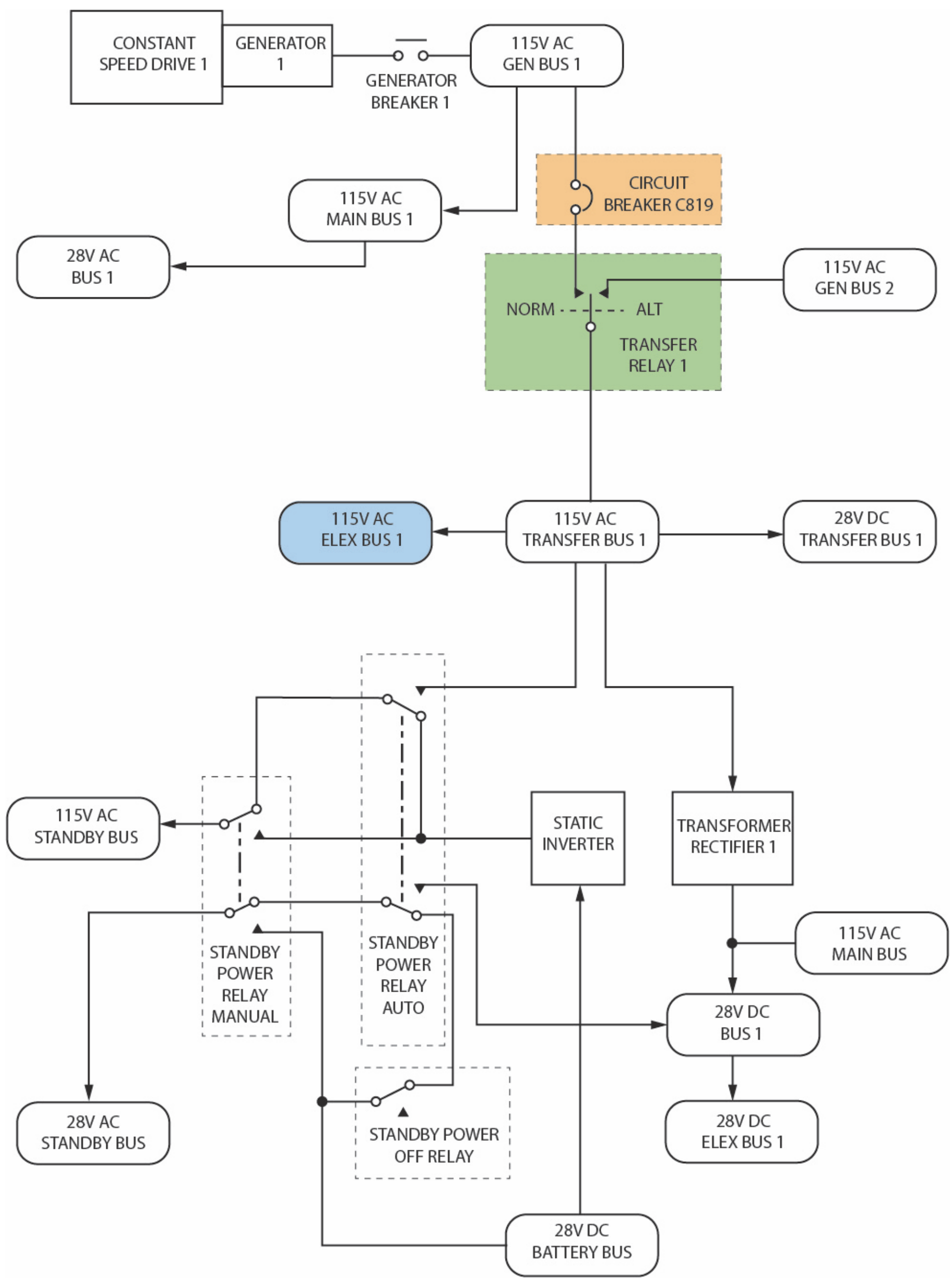

Figure 2

Schematic of electrical power system

All the aircraft systems that failed during the flight either received their electrical power directly from the 115v AC Elex Bus 1 (Figure 2) or were provided with data from Air Data Computer 1 (ADC1), which was connected to this bus. Electrical power to the EGPWS and radio altimeter would also have been lost which meant there would be no reactive windshear warnings, or automatic height call outs and alerts. The CVR and FDR also received their electrical power from the 115v AC Elex Bus 1.

N_1 Limit / Reference Bug

On the Boeing 737-400, the go-around N_1 limit is designed to protect the engines and includes a margin to the N_1 and EGT redlines. If the go-around N_1 limit is exceeded, an engine may experience an over-boost or over-temperature condition. The aircraft manufacturer has stated that there is no connection between the go-around N_1 limit and potential pitch up coupling concerns.

With the autopilot engaged, go-arounds are normally carried out with the autothrottle engaged when the FMC automatically sets the N_1 limit. When the TO/GA[3] button is pushed once, the autothrottle will advance until the aircraft achieves a rate of climb of 1,000 to 2,000 ft/min. If the TO/GA button is pushed a second time, the throttles will advance directly to the full go-around N_1 limit.

When the FMC is inoperable, or the aircraft is flown manually (autothrottle disengaged) the pilots are required to set the thrust to give the required rate of climb and to ensure that they do not exceed the engine N_1 limit. The N_1 limit is obtained from a chart in the QRH, which the pilots use to manually set the N_1 Reference Bug.

Aircraft examination

The AAIB examined G-JMCR at Brussels National Airport with support from the operator and a local maintenance organisation. The aircraft was connected to an electrical ground power supply and the inoperative systems were confirmed. Circuit breaker C819 (Figure 2), which is a 35-amp circuit breaker located between Generator Bus 1 and Transfer Relay 1, was found open as a result of an internal short circuit in Transfer Relay 1. C819 was found to be serviceable. Transfer Relay 1 was replaced, and the aircraft electrical system was tested and found serviceable; the relay had been manufactured in 1985 and been in operation for 22 years before being fitted to G-JMCR in October 2018. No anomalies were found in the service history of the relay.

Footnote

[3] TO/GA, Takeoff /Go-around.

Circuit breaker C819 opening in flight resulted in the loss of electrical power to the following buses:

- 115v AC Transfer Bus 1
- 115v AC Elex Bus 1
- 28v AC Transfer Bus 1
- 28v DC Bus 1
- 28v DC Elex Bus 1

Further systems were lost on landing as a result of the isolation of the 28v DC Standby Bus when the Standby Power Off Relay was deenergised by the Air Ground Switch.

Meteorology

Weather at Brussels National Airport

The METAR and ATIS issued at 1820 hrs for Brussels National Airport, prior to G-JMCR starting its descent, reported a light south-easterly wind, good visibility and some medium level cloud cover with cumulonimbus clouds; the trend indicated a temporary reduction in visibility to 2,000 m in thunderstorms and associated showers of rain and hail.

The METAR at 1850 hrs, when G-JMCR was on the Base leg, reported a light thunderstorm with rain. The trend indicated an expected temporary deterioration in visibility to 2,000 m and moderate thunderstorms with rain and hail.

Windshear

Thunderstorms can produce severe turbulence, lightning, low level windshear and low visibility. The Federal Aviation Administration produced a document[4] explaining the effects of windshear on the operation of aircraft. The following extract is taken from this document:

> *'Vertical wind shear is the type most often associated with an approach. Vertical shear is normal near the ground and can have the most serious effect on an aircraft. The change in velocity or direction can drastically alter lift, indicated airspeed, and thrust requirements. It can exceed the pilot's capability to recover.'*

Aircraft operational documentation

The company operated a mixed fleet of Boeing 737 freighter aircraft, that included the 300, 400 and 800 variants. As a result of different build standards and modification states, there were differences in the electrical and instrument configuration between aircraft.

Footnote

4 https://www.faasafety.gov/files/gslac/library/documents/2011/Aug/56407/FAA%20P-8740-40%20WindShear[hi-res]%20branded.pdf (accessed 18 May 2020)

Aircraft manuals are applicable to individual aircraft with major differences detailed in the Fleet Information Sheet, which is held in the cockpit, and minor differences in the Fleet Differences Book. The QRH is specific to each variant. The Flight Crew Operating Manual (FCOM) includes the Supplementary Procedures for Supplemental Type Certificates (STC) applicable to individual aircraft. Regarding the electrical power supply for the EFIS displays, the FCOM states:

> *'The electronic flight instrument system operates on 115-volt AC power. With loss of all airplane generators* [i.e. loss of both transfer buses]*, the Captain's and the First Officer's EFIS are inoperative. The Standby Instruments provide a backup source of information in this event. On some airplanes, with the loss of all airplane generators, the First Officer's* [right] *EFIS becomes inoperative, but the Captain's* [left] *primary EFIS displays receive power from the AC Standby bus.'*

The pilots were unaware that, on G-JMCR, the left primary EFIS displays would not receive power from the AC Standby Bus in the event of the loss of Transfer Bus 1.

Following this serious incident, the operator identified the aircraft in their fleet configured to enable the left primary EFIS displays to be powered by the AC Standby Bus. Aircraft documentation has been amended to inform pilots of the status of each aircraft.

Relevant QRH and FCOM entries

Use of non-normal checklists

Non-normal checklists (NNC) are used to manage non-normal situations and are contained in the QRH[5] from which the following extracts were taken:

> *'In some multiple failure situations, the flight crew may need to combine the elements of more than one checklist. In all situations, the captain must assess the situation and use good judgment to determine the safest course of action.'*

> *'Non-normal checklist use starts when the airplane flight path and configuration are correctly established. Only a few situations need an immediate response (such as CABIN ALTITUDE WARNING or Rapid Depressurization). Usually, time is available to assess the situation before corrective action is started. All actions must then be coordinated under the captain's supervision and done in a deliberate, systematic manner. Flight path control must never be compromised.'*

Footnote

[5] 737 Flight Crew Operations Manual, Quick reference Handbook, Checklist Instructions, Non-Normal checklists. Boeing Propriety Information. Copyright © Boeing. Reprinted with permission of the Boeing Company.

Relevant QRH entries

NNC.9[6] provides the following information for the yaw damper:

'Condition: The yaw damper is disengaged.

1 YAW DAMPER switch...........OFF then ON

2 Choose one:

YAW DAMPER light ***extinguishes:*** [Yaw damper restored, end of check list]

YAW DAMPER light ***stays illuminated****:*

Go to step 3

3 Do not exceed flaps 30.'

NNC-11[7] provides the following information for a FMC failure on aircraft such as G-JMCR that are equipped with a single FMC:

'Condition: One or more of these occur:

- *Loss of FMC data on a CDU*
- *Loss of FMC data on a navigation display map mode*
- *Illumination of the FMC alert light.*

2 ***When*** *preparing for approach:*

Use the manual N1 set knobs to set the N1 bugs.'

FCOM entry for a go-around

The first actions listed in the FCOM procedure[8] for a Go-Around and Missed Approach includes the requirement to verify that the thrust is sufficient for the go-around or adjust as necessary. This action would require knowledge of the N_1 limit, which would normally be automatically set by the FMC, or in the event of a failure of the FMC by one of the pilots after extracting the relevant $\%N_1$ from a performance table in the QRH.

Footnote

[6] 737-300/-400 Flight Crew Operations Manual [Operators name], NNC.9-Flight Controls, Yaw Damper. Boeing Propriety Information. Copyright © Boeing. Reprinted with permission of the Boeing Company.
[7] 737-300/-400 Flight Crew Operations Manual [Operators name], NNC.11-Flight Management, Navigation. Boeing Propriety Information. Copyright © Boeing. Reprinted with permission of the Boeing Company.
[8] 737-300/-400 Flight Crew Operations Manual [Operators name], Normal Procedures - 21 Amplified Procedures, Go-Around and Missed Approach Procedure. Boeing Propriety Information. Copyright © Boeing. Reprinted with permission of the Boeing Company.

Pilot Flying	Pilot Monitoring
At the same time: • Push the TO/GA switch • Call "FLAPS 15".	Position the flap lever to 15 and monitor flap retraction.
Verify: • The rotation to go-around attitude • That the thrust increase.	
	Verify that the thrust is sufficient for the go-around or adjust as needed.
Verify a positive rate of climb on the altimeter and call "GEAR UP"	Verify a positive rate of climb on the altimeter and call "POSITIVE RATE." Set the landing gear lever to UP.

Analysis

Failure of the 115V AC Transfer Bus 1

The failure of the 115V AC Transfer Bus 1 resulted from a fault in the transfer relay which caused circuit breaker C819 to open with the loss of electrical power from Gen Bus 1 to Transfer Bus 1. This resulted in the loss of electrical power to ADC 1, the primary EFIS displays and analogue instruments on the left side of the cockpit.

A loss of electrical power from a generator should result in the transfer relay automatically operating to allow the remaining generator to provide electrical power to the opposite electrical system through the transfer bus. Failure of electrical power to connect to the transfer bus is normally indicated by the illumination of the TRANSFER BUS OFF caption. However, the nature of the failure meant that the caption did not illuminate; this would have been contrary to the pilots' expectation following the failure of the transfer bus. Consequently, the crew would not have recognised that the partial loss of electrical power was caused by the loss of power to the transfer bus.

Response by the flight crew

This partial electrical failure was a situation that the pilots would not have specifically trained for in the simulator, nor was it one for which their understanding of the electrical system would have provided a clear understanding of the cause and its implications. Consequently, they would have had to manage the situation by assessing which systems had failed and work through the implications using a decision-making tool and the QRH.

The pilots were aware of the thunderstorms in the vicinity of airfield and said they considered the options of continuing with the flight or delaying the approach while they investigated the problem. The commander was of the opinion that manually flying the aircraft while following radar vectors in a busy airspace environment without a serviceable transponder, while diagnosing the problem, would have significantly increased his workload. He assessed both visually and from the ATIS weather reports that he could complete the flight in VMC and had established that the aircraft was in a stable situation with sufficient systems to complete the approach. The pilots had already briefed and prepared the aircraft for a landing on Runway 25R and the commander was confident in manually flying the aircraft and conducting a go-around. The commander, therefore, decided that the safest option was to continue and land at Brussels.

Cockpit workload

It took approximately five minutes from when the electrical failure occurred until the aircraft intercepted the localiser. The PM requested priority to land, declaring a PAN, which would have reduced the time spent manually flying and allowed the aircraft to land before the thunderstorm reached the airfield. The PM requested extra distance from 22 nm to 32 nm; less than one minute later the PF requested immediate vectors. ATC advised they were 17 nm from touchdown and asked if they were ready for the base turn, which the PF accepted. Thirty seconds later the PF declared a MAYDAY and they were vectored tighter onto the localiser, thereby further reducing the distance and time available.

The misreporting of the distance as 6 nm, one minute after being informed it was 12 nm, would have upset the pilots' mental picture and their decision to level off and ask for extra distance would have given them time to assess the situation and review their plan. The correct distance (DME) would have been displayed on the PF's EHSI and on both pilots Radio Distance Magnetic Indicator; however, neither pilot questioned this discrepancy with ATC. Thirty seconds later the PF reported that he was visual with the runway and was cleared for a visual approach. The extra distance, and time, previously requested was not used and as a result of arresting the descent the aircraft was approximately 700 ft above the glideslope.

During this five-minute period the cockpit workload would have been high and the heavy static on the remaining VHF radio would have made communication more difficult.

The approach

The aircraft was flying in twilight, in VMC, towards an active thunderstorm. The pilots reported that the aircraft was stable on the approach at 1,500 ft, with 40° of flap selected which was what was briefed, and the speed bugs set for. However, the QRA advises that if the YAW DAMPER caption is illuminated, '*Do not exceed flaps 30°'.* During the approach, the PF realised that the EGPWS was not working, which meant there would be no reactive windshear warnings or automatic radio altimeter announcements during the approach.

At about 300 ft agl, a heavy rain shower obscured the end of the runway causing the PF to lose visual references and so he commenced a go-around during which he estimated the amount of thrust to set. With the FMC having failed, the N_1 reference bugs should have been manually set, but this had not been actioned. Reports of the aircraft momentarily 'sinking', being slow to accelerate and achieve a positive rate of climb might have been due to the aircraft encountering windshear or insufficient thrust having been set. However, both pilots were of the opinion that they did not encounter windshear and felt that sufficient thrust had been applied.

Cumulative risk

Following the electrical failure, the commander followed a decision-making tool to help diagnose the problem and decide on the best course of action, which would be reviewed as new information became available and the situation developed.

The perception of the pilots was that there had been a significant electrical failure that coincided with a loud "electrical clunk". They would not have known what caused the noise, or if the aircraft had been damaged, and would have needed to weigh the threat in orbiting to assess the problem against continuing with the landing. The pilots had already briefed and prepared for the landing and the commander's assessment was that the best course of action would be to continue and land at Brussels. While the flight and go-around were flown safely, the crew did not complete a number of QRH procedures for systems that were not operating and, therefore, might not have identified and mitigated all the potential threats. While the risk from each of these threats might be small, the cumulative effect can result in a reduction in the overall safety margin.

Time available

During a busy period of flight, the pilots had relatively little time to assess the situation, develop and review their plan as things changed. The time was further reduced by asking ATC for immediate vectors to the approach. They could have provided themselves with more time to assess the situation by being more specific and requesting a minimum distance to start the final approach.

The aircraft had plenty of fuel onboard and the probability of having to go-around could have been reduced by initially orbiting until the thunderstorms had cleared the area.

Conclusion

The electrical failure was caused by a fault in the transfer relay which resulted in the loss of power to a number of electrical buses.

Following the electrical failure, the commander's assessment was that the aircraft was in a stable condition so continued the approach to land at Brussels National Airport. This gave the pilots relatively little time to assess the situation and a number of non-normal checklists actions were not carried out; consequently, the aircraft was incorrectly configured for the approach and landing.

At a late stage of the approach the pilots lost visual references and executed a go-around. The aircraft then orbited while the thunderstorms cleared the airfield and the pilots used the time to further analyse the failure. The second approach and landing were uneventful.

Safety actions/Recommendations

The following safety action has been taken:

> Following this serious incident, the operator identified the aircraft in their fleet configured to enable the left EFIS displays to be powered by the AC Standby Bus. Aircraft documentation has been amended to inform pilots of the status of each aircraft.

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