AAIB
Air Accidents Investigation Branch

AAIB Bulletin 7/2020

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(ALL TIMES IN THIS BULLETIN ARE UTC)

AAIB Field Investigation Reports

A Field Investigation is an independent investigation in which AAIB investigators collect, record and analyse evidence.

The process may include, attending the scene of the accident or serious incident; interviewing witnesses; reviewing documents, procedures and practices; examining aircraft wreckage or components; and analysing recorded data.

The investigation, which can take a number of months to complete, will conclude with a published report.

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

Foonote

[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.

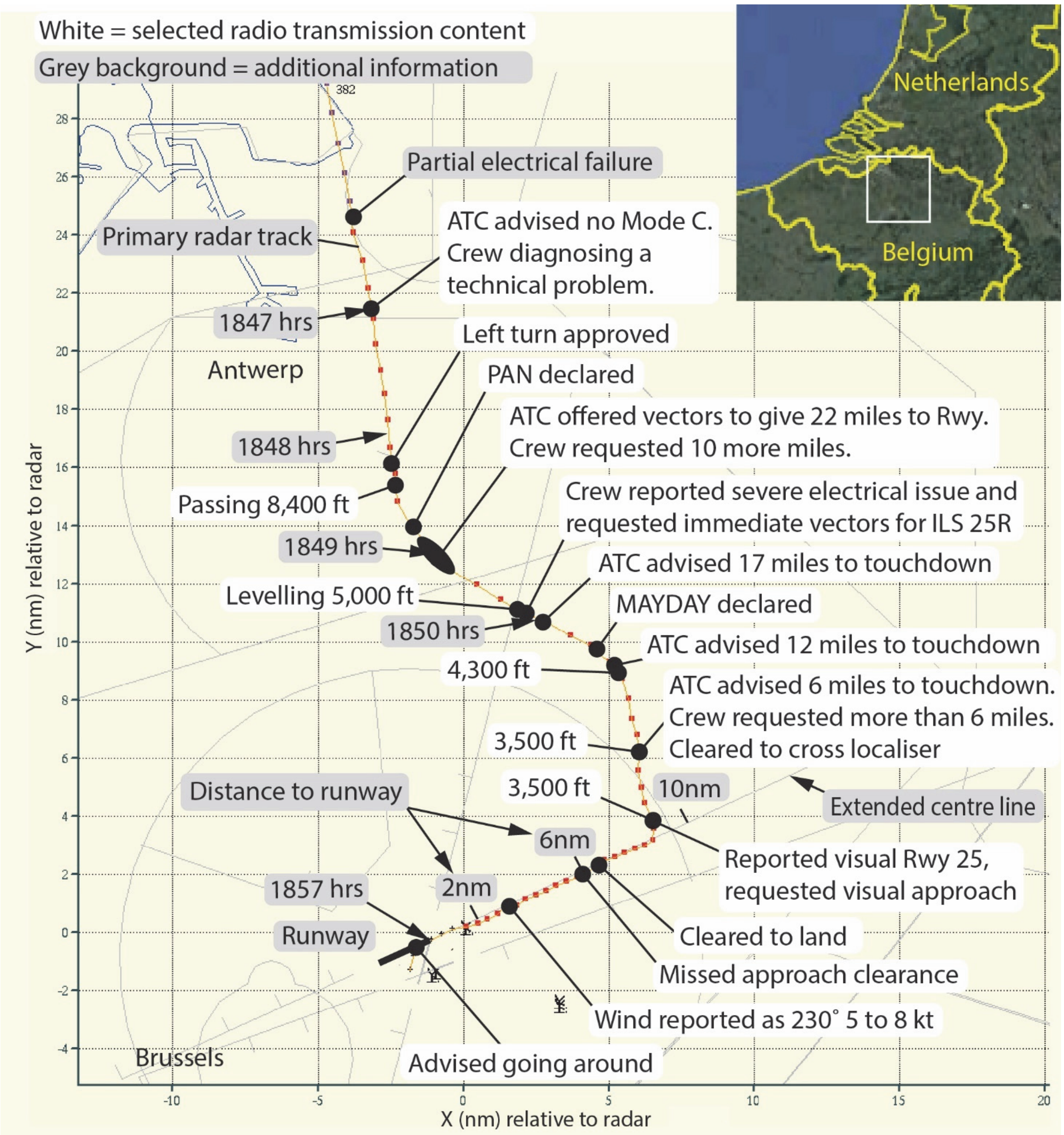

Figure 1

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.

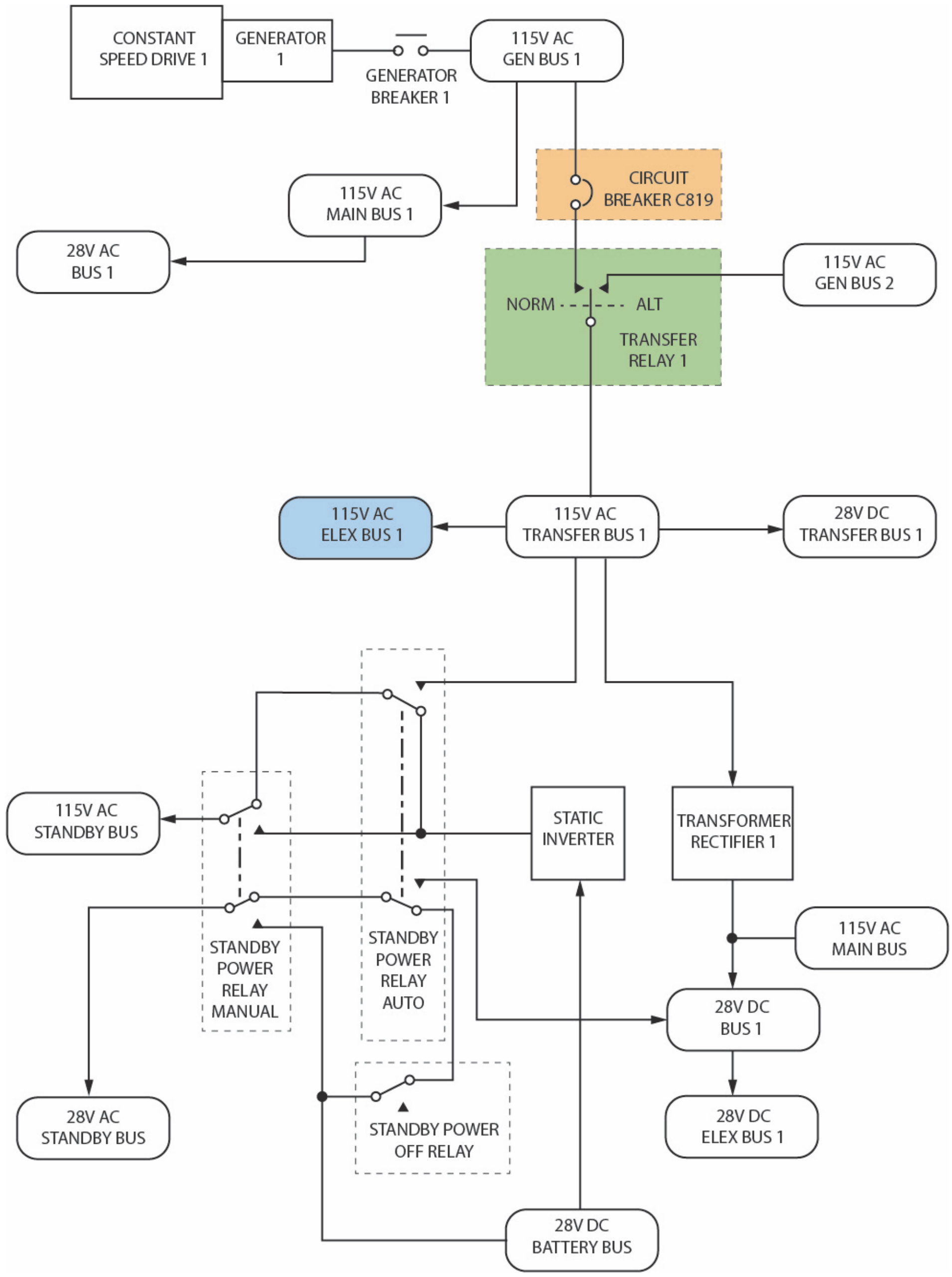

Figure 2

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.

<table>
<tr><th>Pilot Flying</th><th>Pilot Monitoring</th></tr>
<tr><td>At the same time:
• Push the TO/GA switch
• Call “FLAPS 15”.</td><td>Position the flap lever to 15 and monitor flap retraction.</td></tr>
<tr><td colspan="2">Verify:
• The rotation to go-around attitude
• That the thrust increase.</td></tr>
<tr><td></td><td>Verify that the thrust is sufficient for the go-around or adjust as needed.</td></tr>
<tr><td>Verify a positive rate of climb on the altimeter and call “GEAR UP”</td><td>Verify a positive rate of climb on the altimeter and call “POSITIVE RATE.”
Set the landing gear lever to UP.</td></tr>
</table>

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.

Published: 18 June 2020.

ACCIDENT

Aircraft Type and Registration:	Cirrus SR22T, 2-RORO
No & Type of Engines:	1 Continental Motors TSI0-550-K piston engine
Year of Manufacture:	2014 (Serial no: 701)
Date & Time (UTC):	12 May 2019 at 0950 hrs
Location:	A40, near Abergavenny, Wales
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - 2
Injuries:	Crew - 1 (Minor) Passengers - 2 (Minor)
Nature of Damage:	Aircraft destroyed
Commander's Licence:	Commercial Pilot's Licence
Commander's Age:	52 years
Commander's Flying Experience:	1,600 hours (of which 700 were on type) Last 90 days - 70 hours Last 28 days - 30 hours
Information Source:	AAIB field investigation

Synopsis

On takeoff from Abergavenny Airfield the engine of 2-RORO started to produce varying amounts of power, which the pilot and witnesses described as the engine "surging". The power available was insufficient to allow the aircraft to climb away, and it contacted power lines before pitching down and striking a dual carriageway. The aircraft came to rest inverted and was quickly consumed by fire. All three occupants were helped to escape by a passing motorist.

The loss of engine power was probably caused by too much fuel being delivered to the cylinders. Due to the significant damage to the aircraft and parts of the engine, the investigation was unable to determine the cause of the over-fuelling.

History of the flight

The pilot had flown 2-RORO from Denham Aerodrome to Abergavenny Airfield to pick up two passengers. The group would then fly to Manchester for an event later that day. They arrived in Abergavenny around 0930 hrs and were ready to depart at around 0950 hrs; the aircraft was not refuelled. As the pilot prepared for departure, he noted that all the engine indications were normal and completed his pre-takeoff checks, including selecting the electric fuel booster pump ON.

The aircraft accelerated normally along the runway and at around 75 kt lifted off as normal and began to climb. Almost instantly the pilot recognised that the engine was not delivering the expected power. He could hear the sound of the engine rising and falling like it was “surging”, and this sound was also confirmed by other witnesses at the airfield. The pilot felt there was insufficient runway remaining ahead on which to land the aircraft so decided there was little option but to continue the departure, climb away from the ground and carry out a forced landing at the earliest opportunity.

The pilot was aiming to land the aircraft on the dual carriageway, which runs parallel to the airfield, if he could clear the trees running parallel to the runway. However, the aircraft struck the trees and a power cable with its landing gear and this pitched it down rapidly so that it struck the road heavily. Either the initial impact or contact with the central barrier caused the aircraft to invert, and it came to rest against the central barriers on the far carriageway. A fire started during the accident sequence. Figure 1 shows the accident site with the airfield in the background.

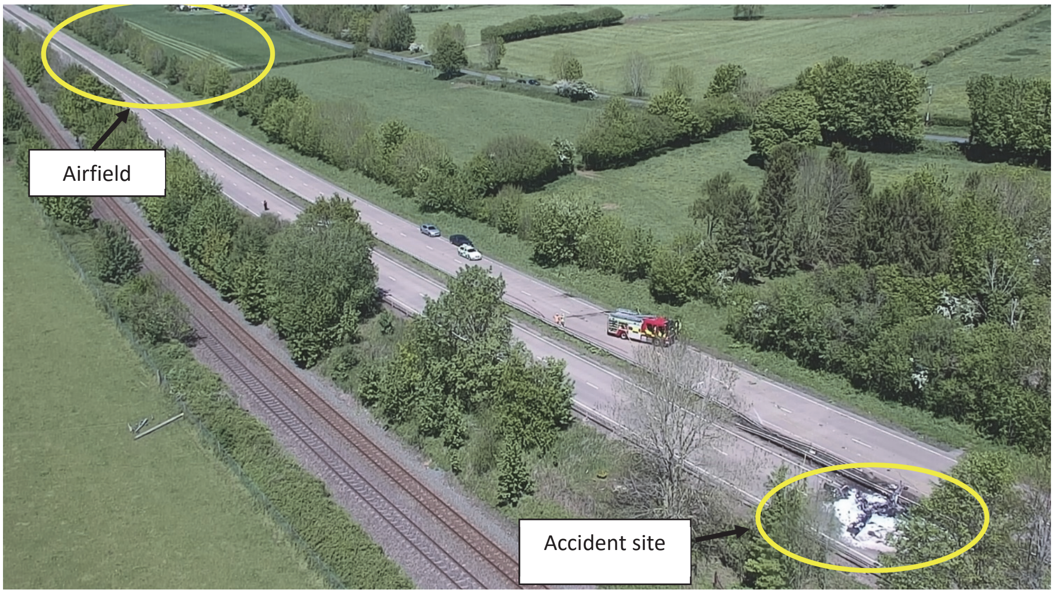

Figure 1

Accident site with Abergavenny Airfield in the background

All three occupants were trapped in the aircraft due to the inverted attitude jamming the doors closed. Whilst the aircraft is equipped with a hammer to break the windows during such an event, the occupants were unable to find it in the confusion and disorientation of being upside down. One of the passengers and a passer-by who rushed to help were able to break one of the windows. The passer-by pulled out the three occupants one by one who were then able to run away from the fierce fire. The occupants suffered only minor injuries. Figure 2 shows the aircraft on fire after the occupants escaped. The pilot estimated that the flight time from lift off to striking the road was less than 30 seconds.

The aircraft was equipped with a ballistic recovery system (BRS) as well as an oxygen bottle and both items were consumed in the fire. The oxygen bottle caused a significant explosion shortly after all the occupants had been assisted from the wreckage. On arrival at the scene the fire brigade was advised about the BRS by the pilot and as a result, once the fire was under control, they contacted the AAIB for advice to ensure that the BRS was safe and that no additional precautions were needed.

Figure 2
Aircraft fire after the occupants' escape

Accident site

The aircraft came to rest against the central reservation barriers of the northbound carriageway of the A40 approximately one mile south of Abergavenny, Monmouthshire. There were clear witness marks on the carriageway indicating that the aircraft slid from the initial impact point to its final resting place. Figure 3 shows the accident site and the marks on the road.

The majority of the aircraft was consumed by fire, with little behind the engine firewall surviving. The engine, however, was relatively intact. The wreckage was recovered by the emergency services so that the road could be re-opened, it was then moved to the AAIB at Farnborough for further examination.

Figure 3
Accident site showing the ground marks

Recorded information

2-RORO was fitted with a recoverable data module (RDM) in the tail. However, neither the recorder nor the protected memory module within it could be located. The wreckage had been recovered from the roadside and moved to a storage yard before subsequently being transported to the AAIB. It could not be established if the memory module had not survived the intense fire in the area of the tail, or if it was lost in the subsequent movements of the wreckage. The RDM would have recorded flight and engine data.

The aircraft was fitted with a Mode S transponder, but the aircraft did not reach a height at which its transmissions were picked up by any receiver.

Aircraft information

The Cirrus SR22T is a four-seat aircraft largely constructed from composite material. The aircraft is fitted with a Continental TSIO-550-K1B six-cylinder twin turbocharged piston engine. The cylinders are numbered one to six[1]. The ignition system consists of two engine-driven magnetos and two spark plugs per cylinder. Ignition and magnetos are controlled by a four-position switch in the cockpit. The engine drives a three-blade, composite, variable-pitch constant speed propeller.

Aircraft fuel system

The SR22T is fitted with an integral fuel tank in each wing. Fuel is fed by gravity to the associated tank collector sump, where an engine-driven pump draws fuel through a filter and a selector valve (with positions LEFT/RIGHT/OFF) to pressure feed the engine fuel injection

Footnote

1 No 1,3 and 5 cylinders are on the right side of the engine as seen from the pilot seat with No 2,4 and 6 on the left side of the engine. No 1 and 2 cylinders are closest to the pilot at the back of the engine.

system. An electric fuel pump is fitted upstream of the engine-driven pump to provide fuel for engine priming and for vapour suppression. A schematic diagram of the aircraft fuel system can be found in Figure 4.

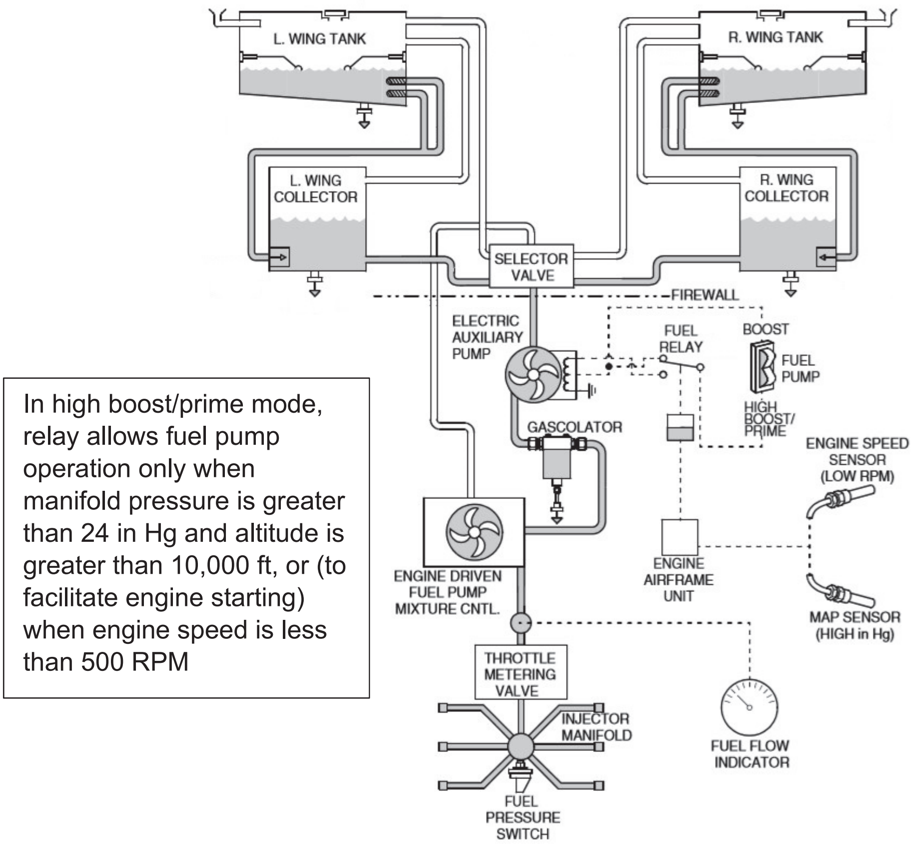

Figure 4

Cirrus SR22T fuel system incorporating software update v0764.36

Electric fuel pump operation is controlled through a fuel pump rocker switch in the cockpit. The switch has a lower pressure BOOST position and a higher-pressure HIGH BOOST/PRIME position. Selecting BOOST energizes the fuel pump in low-speed mode regardless of engine speed or manifold pressure to deliver a continuous 4-6 psi boost to the fuel flow for vapour suppression in a hot fuel condition. The manufacturer's checklist suggests selecting the pump to BOOST before engine start (HIGH BOOST/PRIME before BOOST for a cold weather start) and leaving it at BOOST until the aircraft reaches cruise altitude. The pump should then be selected to BOOST before landing. The manufacturer also recommends the pump be selected to BOOST for any manoeuvring flight. The system is fitted with a lockout relay to ensure that HIGH BOOST/PRIME is only used for engine start (when the engine speed is less than 500 rpm) or for operation at high power settings (when the manifold pressure is greater than 24 in Hg). A software modification was introduced in November 2018 which also locked out the high boost setting below 10,000 ft. This software update was embodied in 2-RORO in January 2019.

The lockout relay limits the electric fuel pump to the lower pressure BOOST even if the switch is selected to HIGH BOOST/PRIME. During takeoff, although the manifold pressure would have been in excess of 24 in Hg, the aircraft was below 10,000 ft altitude and therefore the lockout relay should have limited the fuel flow. The altitude restriction was introduced by a software update after several incidents with this aircraft type where the electrical fuel boost system was suspected of causing over-fuelling[2] to the engine resulting in black soot deposits and reported engine "surging".

The fuel supply is metered in the throttle metering valve which selects the appropriate fuel flow for the demanded power and environmental conditions. Excess fuel is then returned to the selected tank via the return line. The metered fuel passes to a flow divider and is delivered to the individual cylinders.

Ballistic recovery system

The SR22T is fitted with a BRS that can be deployed in the event of loss of control, failure of the aircraft structure, or other in-flight emergencies. Once deployed, a large parachute lowers the aircraft to the ground. The aircraft did not reach a height at which deployment of the system would have been a successful option.

Maintenance history

2-RORO held a valid Certificate of Airworthiness and had been maintained in accordance with an approved maintenance programme. The aircraft had its last Annual Inspection on 8 August 2018. This included a magneto timing check and an inspection of the spark plugs, which were all recorded as serviceable and within limits.

The pilot had flown the aircraft during the previous week and noted no anomalies with, or adverse performance from the engine. The flight to Abergavenny on the morning of the accident was also normal.

Survivability

The pilot reported that because the aircraft was inverted he found it difficult to locate the emergency egress hammer, which was in the central armrest, to break the windows. Disorientation when an aircraft is in an abnormal attitude can mean people find it difficult to locate seat belt releases and emergency equipment. The cabin space remained intact through the accident sequence, and once the window had been broken the occupants found they could escape relatively easily despite being inverted.

Weight and balance

The aircraft was under its maximum takeoff weight and within its centre of gravity limits.

Footnote

[2] Over-fuelling is where the fuel-to-air mixture delivered to the engine is too rich in fuel for the conditions.

Aircraft performance

Calculations of the aircraft takeoff performance, using figures provided by the aircraft manufacturer and assuming a normally operating engine, indicated that the runway available was more than adequate for the takeoff distance required. These calculations also showed that the aircraft should have had no difficulty in clearing the trees in the departure route.

Meteorology

Weather conditions at the airfield are automatically recorded. At the time of the accident the wind was from 140° at 5 kt, with a temperature of 13°C. There was no cloud below 5,000 ft aal and the QNH was 1033 HPa. There had been no rain in the previous 24 hours and the grass was dry.

Engine examination

The engine was examined externally prior to strip down. Although it sustained thermal damage from the post-accident fire, this was concentrated at its bottom and rear. There were no external pre-accident anomalies visible with any of the components. The spark plugs were removed and examined. All were coated in a dark black soot with oil also coating all but the No 2 top and No 5 bottom sparkplugs (Figure 5). The No 1 top, No 4 bottom and the No 6 bottom sparkplugs had fractured centre insulators. All the sparkplugs displayed what the engine manufacturer described as a '*severe worn-out wear condition*', as the central electrodes on all sparkplugs had eroded to an elliptical or diamond shape. The sparkplugs were tested and the ones with the cracked insulators failed to produce a spark.

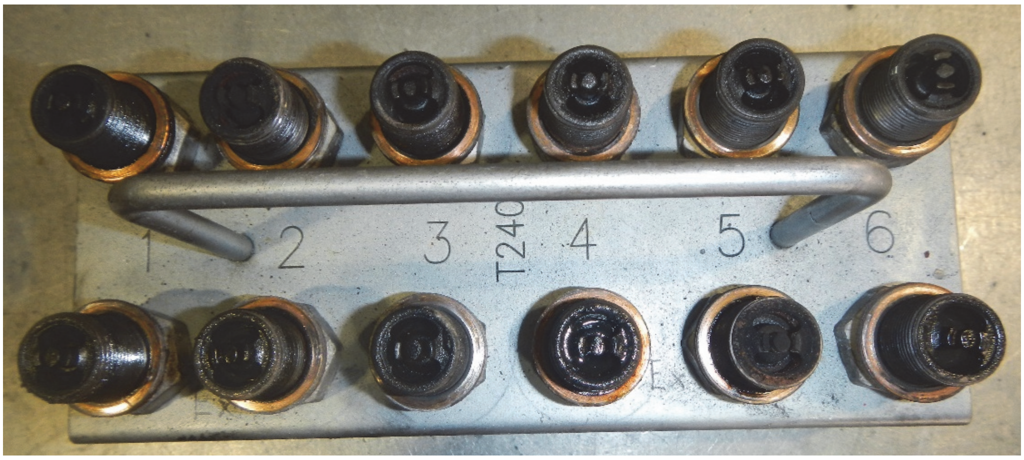

Figure 5

Spark plugs removed during engine strip

The engine exhaust system risers and manifolds remained attached to the engine. The turbochargers and wastegates were removed and examined. No pre-accident anomalies were evident. The turbocharger turbines and their respective impellers rotated normally.

Both magnetos remained secured to the engine. Examination showed that the magneto-to-engine timing was not to specification. It was not established if this was also the case before the accident. However, on removal from the engine both the left and right magneto internal timing were also not to specification. The magnetos were placed on a test stand and functionally tested. Both produced a spark from each lead in the correct firing order throughout the operational speed range.

The engine-driven fuel pump had sustained significant thermal damage and it was not possible to functionally test it. Disassembly revealed there were no pre-accident anomalies with its internal components. The throttle body was intact and after removal from the engine it was tested against the production specifications. Although the results showed that it was not calibrated to the Aircraft Maintenance Manual specification, the differences were slight with a somewhat leaner condition in the mid-throttle range. The fuel manifold valve functioned as designed. All the fuel nozzles were clear and free from obstructions. The engine oil system was normal with no signs of pre-accident anomalies. Neither the fuel pump rocker switch nor the electric fuel pump and its associated lockout relay were located in the wreckage, and it was considered likely that they had been destroyed in the post-accident fire.

All six cylinders remained attached to the crankcase and produced compression when the crankshaft was manually rotated, and all rockers/valves moved normally. None of the cylinders' internal components showed any significant combustion deposits. On removal it was seen that all cylinder heads and intake valves were covered in black soot. Cylinder No 5 also displayed evidence of lean-mixture piston head and cylinder head erosion as shown in Figure 6.

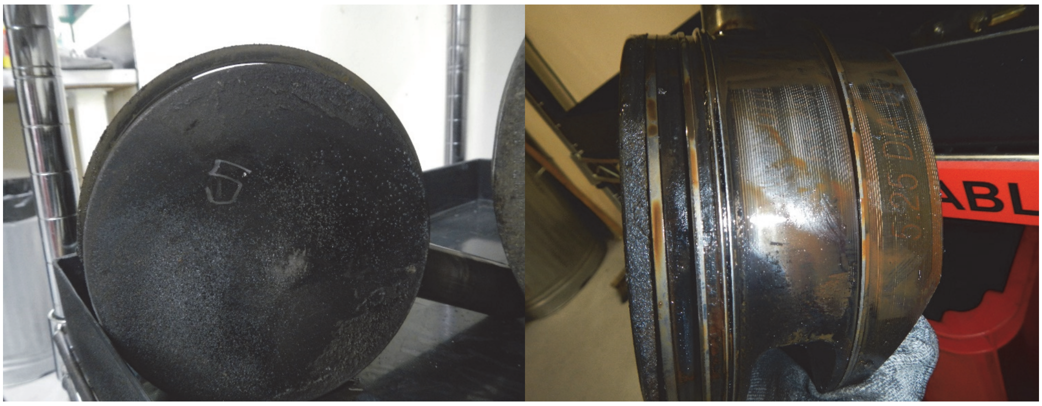

Figure 6

Cylinder No 5 showing the dark soot deposit and the lean-mixture piston face and cylinder head erosion

The crankcase, crankshaft, connecting rods, camshaft and assessor gears were all intact and showed no mechanical anomalies.

The propeller governor was stripped, and it showed no pre-accident anomalies and that the propeller was rotating when the aircraft struck the ground. Assessment of the propeller pitch change mechanism confirmed that the propeller was in fine pitch at the time it struck the ground.

Analysis

On takeoff from Abergavenny Airfield, 2-RORO suffered a loss of engine power and could not climb away adequately. The aircraft struck power cables, pitching it down onto the dual carriageway which runs alongside the airfield. The aircraft came to rest inverted and a fire developed which quickly consumed much of the aircraft. The pilot and two passengers were helped from the aircraft by a passing motorist.

The pilot and witnesses described the engine sounding like it was "surging" with varying power. The propeller and its governing system were examined and considered not to exhibit any pre-impact damage, and therefore the governing system was ruled out as a possible cause of the loss of power.

The pilot's description, together with the soot on the cylinders and intake valves, suggested the engine was running with a rich fuel mixture (over-fuelling). However, the engine itself revealed a longer-term issue with magneto timing, lean running (under-fuelling) and spark plug damage. These longer-term faults could all be linked with the magneto timing issues causing both the spark plug damage and the cylinder damage but could not explain the engine malfunction on the day of the accident. The longer-term faults may have eventually caused a loss of power on the engine, but they were not the cause of the failure on the accident flight.

Rich running could have been caused by a malfunction in the electric fuel pump system or fuel metering system, or by a blockage or restriction in the fuel return lines, possibly elevating the fuel delivery pressures and flows to the engine. The electric fuel pump and its associated lockout relay were destroyed in the post-accident fire so could not be examined or tested. The throttle body was tested and found to be outside production specifications, although the differences were slight and tended towards lean running rather than rich. 2-RORO had software which, to prevent over-fuelling on takeoff, added an altitude restriction to the conditions in which the HIGH BOOST/PRIME relay would allow increased fuel flow. It should not therefore have been possible for over-fuelling from the electric fuel pump to occur even if the switch had been selected to HIGH BOOST/PRIME. The aircraft and engine examination did not establish if there was any fault or malfunction in the relay or the rest of the fuel system. It was not therefore possible to identify the cause of the over-fuelling on the takeoff at Abergavenny.

Had the memory module of the recorder been recovered, it would have helped the investigation understand the accident flight and the long-term health of the engine through trends in temperatures and pressures over time. Without it, the investigation was left with physical evidence in the engine of longer-term issues related to lean running (under-fuelling) and short-term issues related to over-fuelling. It became clear from the engine examination that the loss of power on the accident flight was unrelated to the longer-term engine issues.

Conclusion

The loss of power after takeoff experienced by 2-RORO was probably caused by over-fuelling leading to a mixture too rich for the engine. Both the engine and aircraft manufacturers have investigated cases where an engine has been over-fuelled when the aircraft is at a low altitude but with a high power setting, such as with the accident takeoff. The manufacturer developed a software modification to remove this risk by preventing the HIGH BOOST/PRIME function being active below 10,000 ft altitude with the manifold pressure above 24 in Hg. This software modification was embodied on 2-RORO at the time of the accident. The cause of the over-fuelling was not determined because many components of the fuel system as well as the data recorder were not located or were destroyed in the post-impact fire.

Published: 18 June 2020.

ACCIDENT

Aircraft Type and Registration:	DJI M600 Pro (UAS, registration N/A)
No & Type of Engines:	6 electric motors
Year of Manufacture:	2019 (Serial no: 2016DP6137)
Date & Time (UTC):	13 December 2019 at 1521 hrs
Location:	Wallsend, Tyne and Wear
Type of Flight:	Aerial Work
Persons on Board:	Crew - None Passengers - None
Injuries:	Crew - N/A Passengers - N/A
Nature of Damage:	Propellers, arms, landing gear, gimbal and camera lens damaged
Commander's Licence:	Not applicable
Commander's Age:	31 years
Commander's Flying Experience:	44 hours (of which 6 were on type) Last 90 days - 8 hours Last 28 days - 4 hours
Information Source:	AAIB Field investigation

Synopsis

The UAS, a DJI M600 Pro, was being operated in an automated flight mode to survey a construction site when a GPS-compass error caused the aircraft to revert to a flight mode that required manual control. By the time that the pilot and observer realised that it was not responding to the return-to-home (RTH) function, visual line of sight was lost when the aircraft drifted with the wind beyond a line of trees. It subsequently collided with the roof of a house before falling into the property's rear garden. No persons were injured.

The pilot, and the observer who was also a pilot, had operated UASs since 2018 and had the required permissions from the UK CAA. Both pilots had relied predominantly on the automated flight capability of their aircraft and had not, nor were required to have, practised for emergencies since completing their flying training in 2018. One Safety Recommendation is made to the UK CAA.

History of the flight

The UAS, a DJI M600 Pro, was being operated commercially[1] to survey a construction site. The aircraft was to be flown using its automated flight mode[2] with the survey scheduled

Footnote

[1] A commercial operation involves a flight or flights 'in return for remuneration or other valuable consideration'. The full definition is available at http://www.legislation.gov.uk/uksi/2016/765/article/7/made (November 2019).

[2] In automated flight mode the aircraft would takeoff, fly between preset positions and then land without the intervention of the pilot.

to take place over two days. The first day's flying passed without incident and, on 13 December 2019, the pilot[3], and an observer who was also a pilot, returned to complete the site survey.

By 1500 hrs, three flights had been completed without incident and the aircraft, with batteries that were almost fully charged at 97%, was being prepared for its final flight of the day. It was positioned to take off from the same location as the previous flight and was configured to climb to 400 ft amsl where it was to then automatically follow a route around the site before returning to land. The pilot held the controller and the observer stood a short distance away. There was no precipitation and the visibility was estimated at 2 km with the wind from a west-south-westerly direction at about 13 kt.

The takeoff was normal but, as the aircraft approached 100 ft amsl (a height of about 65 ft agl), the pilot noticed that a GPS-COMPASS ERROR was displayed on the controller. The aircraft stopped climbing and proceeded to fly in an east-north-easterly direction at a ground speed of about 13 kt, whilst maintaining an altitude of about 100 ft amsl (Figure 1). The pilot and observer reported that they were initially taken by surprise. The pilot then selected the return-to-home (RTH)[4] function on the controller several times, but the aircraft did not respond. Within about ten seconds, the pilot and observer lost visual line of sight (VLOS) with the aircraft when it travelled beyond a line of trees located at the boundary of the construction site. No manual flight control inputs were made using the controller.

The aircraft proceeded to fly overhead a large industrial area before approaching a housing estate located 300 m from where it had taken off. The aircraft had continued to maintain its altitude; however, its relative height above the ground reduced as it approached the housing estate due to the rising terrain. The recorded logs from the aircraft showed that, at 1521:07 hrs, the aircraft collided with the roof of a house before falling into the rear garden of the property (Figures 2 and 3). There were no persons in the garden at the time. The aircraft's propellers, arms, landing gear, gimbal and camera lens were damaged. The flight time from when the GPS-compass error had occurred and the aircraft colliding with the house was 75 seconds. The controller had remained in radio contact throughout the flight.

The pilot subsequently notified the police that the aircraft was missing, before preparing another aircraft to search the immediate area. However, shortly after takeoff, a SIGNAL-INTERFERENCE error message was displayed on the controller and the pilot immediately landed the aircraft. The accident aircraft was subsequently found by the owner of the house who notified the police. The pilot and observer, in accordance with procedures, submitted a safety report within 48 hrs to the EASA[5].

Footnote

3 The Air Navigation Order 2016 (Amendment 13 March 2019) refers to a person in control of an unmanned aircraft as a remote pilot. In this report, the remote pilot is referred to as 'pilot'.

4 In normal operation the RTH function would automatically land the aircraft at its takeoff position.

5 www.aviationreporting.eu (the appropriate website in December 2019).

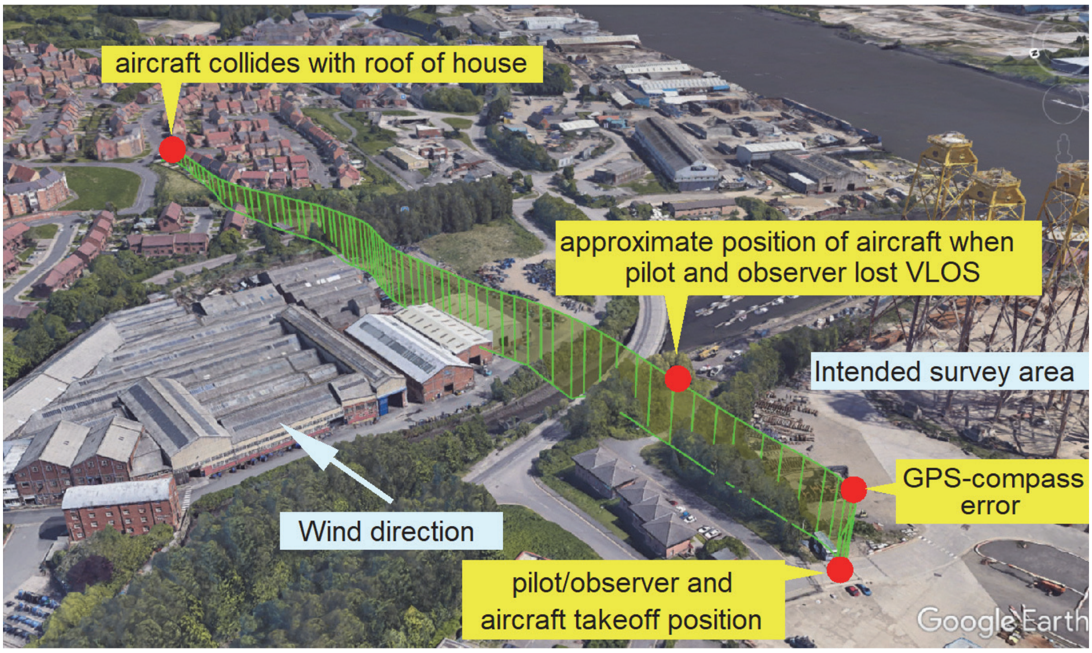

Figure 1

Recorded GPS flightpath of aircraft

Figure 2

Accident location

Figure 3
The aircraft after falling into the garden

UAS information and previous GPS error

The M600 Pro is a six-rotor aircraft and has a maximum takeoff mass of 15.1 kg (Figure 4) and its flight controller is shown in Figure 5. During the accident flight, the aircraft's mass was 12.8 kg, which included an underslung camera. The accident aircraft had been purchased new in August 2019 and had accumulated just over six hours flight time.

Figure 4

M600 series aircraft
The accident aircraft was fitted with three GPS antenna (white circular components)
(photograph used with permission)

Figure 5

M600 Pro aircraft controller

GPS–compass error

The aircraft used a combination of GPS, inertial and magnetic heading (referred to by the manufacturer as 'compass') information to maintain a fixed position when hovering, automatically navigate and to RTH. If either the GPS or compass information is lost, the aircraft will revert to a manual flight mode referred to as attitude (ATTI). In ATTI mode, the aircraft will maintain its altitude and attitude using its internal barometric and inertial sensors, but its position is no longer stabilised by the GPS. This means that the aircraft will drift with the wind in ATTI mode.

When in ATTI mode, the pilot uses the controller's two joysticks to control the aircraft's lateral and vertical position. If ATTI mode is lost, the aircraft will revert to full-manual mode, whereby altitude and attitude stabilisation is not available. The DJI 600 could be placed in ATTI mode by a selection on its controller but it was not possible to select full-manual mode.

The recorded log from the accident flight was analysed by the aircraft manufacturer, who stated that the reversion to ATTI mode had been caused due to a mismatch between the aircraft's GPS derived heading and its magnetic compass heading data. This was attributed by the manufacturer to have been caused by signal interference that had affected the magnetic compass. The error had continued throughout the flight. The manufacturer advised that if the error had subsequently cleared, the automated flight modes would have been re-established.

The pilot reported that some weeks before the accident the aircraft had also reverted to ATTI mode when a problem occurred with the GPS. However, on this occasion the aircraft was being flown in a GPS-assisted mode in combination with joystick control inputs and therefore it had not been necessary for the pilot to quickly transition to using the joysticks as was required during the accident flight. The aircraft was landed safely during this previous event.

Pilot training and emergency procedures

The CAA required that any person or organisation operating a UAS with a mass of no more than 20 kg[6] for commercial work in the UK required permission, which was commonly referred to as Permissions for Commercial Operations (PfCO). The applicant for a PfCO needed to show pilot competence and provide an operations manual, which was required to include actions to take in an emergency. The operator of the accident aircraft held a PfCO and had several trained pilots that operated under this permission.

Pilot competence was demonstrated through a combination of ground training and a practical flight assessment by an authorised training facility. Both the pilot and observer had completed their training in November and October 2018 respectively, which had included flying a multirotor UAS in ATTI mode and dealing with emergency situations such as an uncommanded fly-away.

Footnote

6 The ANO refers to a UAS falling into this category as a Small Unmanned Aircraft (SUA).

A PfCO was renewed annually and required that each pilot was to have flown at least two hours in the last three months prior to renewal. The CAA did not require, nor provide guidance on, practising for emergencies or maintaining manual flying skills as part of the PfCO renewal. Despite not being a requirement, the pilot and observer had undertaken an additional day of training, part of which involved ATTI mode flying, prior to being assessed.

The operations manual provided by the operator of the accident aircraft included emergency actions to take if an error resulted in reversion to ATTI mode. These instructed the pilot to '*Call ATTI mode and initially maintain the hover to assess the controllability'* and '*If content that control can be maintained then recover the aircraft to the landing point'*.

Discussions with a pilot training organisation for multi-rotor UAS indicated that, like other forms of aviation, manual flying is a perishable skill and that they recommended that UAS pilots should routinely practise manual flying in conjunction with actions to take in an emergency.

Pilot and observer recency

The pilot and observer stated that although they flew their multi-rotor UASs frequently, they were predominantly flown using automated flight modes. Neither the pilot nor observer had practised for emergencies since completing their PfCO training in 2018 although, in a previous incident, the pilot had successfully recovered control of the UAS when it lost GPS and reverted to ATTI mode.

Risk of injury due to falling objects

The AAIB is not aware of any research relating to the potential for injury from a falling UAS. However, in the 1990's a dropped object prevention scheme (DROPS)[7] was introduced as part of a safety initiative by the UK Oil and Gas industry. The program has since expanded to include about 200 organisations, with the development of a DROPS analysis calculator[8]. This provides an indication as to the possible outcome[9] of a blunt object in free fall striking a person wearing personal protective equipment (ie hard hat, eye protection).

Analysis using the DROPS calculator indicated that a blunt object with a mass of more than 2 kg (the mass of the accident aircraft was 12.8 kg) falling from a height of 6 m (~20 ft) agl (the approximate height that the aircraft fell from the roof of the house) could result in a fatal injury to someone wearing a hard hat.

Footnote

7 https://www.dropsonline.org [accessed 16 September 2019]

8 https://www.dropsonline.org/resources-and-guidance/drops-calculator/e-drops-calculator/. This calculates the potential energy of an object (Mass(m) x Height(h) x Gravitational Acceleration). The DROPS Calculator is a guide only and is intended to give a general idea of the potential severity of a dropped object. [accessed 16 September 2019]

9 It is not possible to be definitive due to varying factors such as where an object strikes a person or if it penetrates the body.

Analysis

Following the GPS-compass error, the aircraft had reverted to ATTI mode. This required the pilot to take manual control of the aircraft to control its flightpath. However, the pilot and observer focused their attention on selecting the automated RTH function, but this mode was not available due to the GPS-compass error. The controller was in radio contact with the aircraft, which would have responded to manual flight control inputs had they been made.

Within about ten seconds of the error occurring, the pilot and observer lost VLOS with the aircraft when it drifted with the wind beyond a line of trees. After this, a safe landing was unlikely due to the built-up nature of the surrounding area and the lack of references available to the pilot of the aircraft's relative position, heading or height.

The aircraft manufacturer attributed the GPS-compass error to signal interference that affected the aircraft's compass. This interference had remained present for the duration of the short flight. The evidence indicates that this interference also affected the aircraft that was to be used to search for the accident aircraft. The source of the interference was not established.

The DROPS analysis indicated that a mass of more than 2 kg falling from the roof of the house could have resulted in a serious or even fatal injury to people if they had been struck. The aircraft mass, at 12.8 kg, was well in excess of this figure and therefore it is very likely that serious injuries would have occurred even if the person struck was wearing a hard hat for protection.

The aircraft operator's operations manual provided actions to take in the event of an emergency, which included the need to take manual control if an error resulted in the aircraft reverting to ATTI mode. However, the last time that the pilot and observer had practised for emergencies was when they had completed their training in 2018. This training had included an additional voluntary day that involved flying a UAS in ATTI mode but, since then, their day-to-day operations had meant that the ATTI mode was not used routinely and therefore pilots were not well-practised using this mode.

There is currently no requirement for operators to routinely practise for emergencies, such as an uncommanded fly-away. However, manual flying is a perishable skill that UAS operators may need to rely on in the event of an emergency. Therefore, the following Safety Recommendation is made:

Safety Recommendation 2020-017

It is recommended that the Civil Aviation Authority require that operators issued with a Permissions for Commercial Operations (PfCO) include in their operations manuals the need to practise routinely the actions to take in the event of emergencies, and specify how pilots will remain competent at maintaining manual control of their aircraft in the event that automated flight modes are lost.

Conclusion

The pilot was required to take manual control of the aircraft following the loss of its automated flight modes due to signal interference. However, no manual control inputs were made, and the aircraft subsequently drifted with the wind until it collided with a house roof and fell to the ground. No persons were injured.

Operators holding a PfCO issued by the CAA are not currently required to practise routinely for emergencies or demonstrate the ability to fly their aircraft in a degraded flight mode. These skills are perishable but, as this accident shows, they may be needed at any time; it is important that they are maintained to prevent a risk of injury to people or damage to property. To address this, one Safety Recommendation has been made to the CAA.

Safety action taken

The operator of the accident aircraft stated that it had taken the following safety action:

> The operator's pilots have undergone refresher training on responding to emergency situations and operating their multi-rotor UASs in the ATTI flight mode.

Published: 25 June 2020.

AAIB Correspondence Reports

These are reports on accidents and incidents which were not subject to a Field Investigation.

They are wholly, or largely, based on information provided by the aircraft commander in an Aircraft Accident Report Form (AARF) and in some cases additional information from other sources.

The accuracy of the information provided cannot be assured.

SERIOUS INCIDENT

Aircraft Type and Registration:	Antonov AN12, UR-CKL
No & Type of Engines:	4 Ivchenko AI-20 turboprop engines
Year of Manufacture:	1971
Date & Time (UTC):	30 September 2019 at 1120 hrs
Location:	Liverpool Airport
Type of Flight:	Commercial Air Transport (Cargo)
Persons on Board:	Crew - 7 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Damage to the outer left wing leading edge
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	56 years
Commander's Flying Experience:	14,802 hours (of which 14,492 were on type) Last 90 days - 56 hours Last 28 days - 21 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

Synopsis

The aircraft's left wing struck a lighting stand whilst leaving its parking stand. The aircraft had been parked in a position where the crew could not see the stand's ground guidance markings and there was no marshaller to guide them.

History of the flight

The operator had been involved in a series of flights to Liverpool Airport, but the airport did not have access to a suitable tow bar for use with the aircraft each time it had arrived. As a result, the aircraft had been parked on Stand 41, described in the AIP[1] as a 'taxi in/push back' stand, under the guidance of a marshaller, so that it was in a position to be able to taxi off the stand without needing to be pushed back.

On the day of the accident, as before, the aircraft had been parked after its arrival under the guidance of a marshaller on Stand 41. By guiding the aircraft to turn onto the stand during the parking manoeuvre this had resulted in the left wing protruding between two lighting stands located at the southern edge of the stand area. The intention was for the aircraft to continue the turn when taxiing off the stand which would allow its wing to clear the lighting stand in front.

Footnote

1 UK Aeronautical Information Publication.

The aircraft was unloaded and prepared for its next flight by the flight crew. Having started the engines, the crew called ATC for taxi clearance and were cleared to taxi for Runway 27. They later stated that they had no taxi markings to guide them off the stand and no ‘Follow Me Vehicle’ to follow. There was a ground handling agent in attendance, although it was not his role to provide marshalling guidance to the crew.

The crew stated they taxied the aircraft forward, but after moving about 15-20 m they felt an impact and immediately stopped the aircraft, shutting down the engines. On inspection it became apparent that the leading edge of the outer section of the left wing had collided with the lighting stand situated in front of the aircraft.

Airfield information

The airport operations department reported that parking the aircraft on Stand 41 offered a solution to the absence of a suitable tow bar. This had not caused any issues during previous visits by the aircraft to the airport. It was daylight at the time of the accident and it was considered the presence of the lighting stands and the aircraft’s position relative to them would have been obvious to the crew. The operations department also believed that had the crew had any concerns about taxiing off the stand they would have called ATC for assistance.

Comment

The airport had accommodated the fact an appropriate tow bar was not available for the aircraft by parking it on an existing stand in a manner not intended for that stand. Whilst this enabled the aircraft to leave the stand without needing to be pushed back, it had put the wing in a position where it was in danger of colliding with the lighting stand. This foreseeable outcome might have indicated the need for appropriate guidance to be made available to, and requested by, the crew to ensure adequate clearance from the lighting stand.

Safety action

> The airport has re-designated Stands 11-14 and 33-41 to allow parking by self-manoeuvring. The AIP entry has been updated to inform pilots that under such circumstances a marshaller will be available during departure and to instruct pilots to request assistance at any time they need it when taxiing.

SERIOUS INCIDENT

Aircraft Type and Registration:	Eurocopter AS350B2, G-PDGF
No & Type of Engines:	1 Turbomeca Arriel 1D1 turboshaft engine
Year of Manufacture:	2000 (Serial no: 9024)
Date & Time (UTC):	3 March 2020 at 1430 hrs
Location:	Glencoe, Argyll, Scotland
Type of Flight:	Aerial Work
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	No damage to the helicopter or lifting equipment, underslung load destroyed
Commander's Licence:	Commercial Pilot's Licence
Commander's Age:	66 years
Commander's Flying Experience:	20,600 hours (of which 8,150 were on type) Last 90 days - 30 hours Last 28 days - 30 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot and additional enquiries by the AAIB

Synopsis

During the refurbishment of an electricity line, G-PDGF was carrying an underslung load consisting of a 700 kg wooden pole which was then inadvertently released. The pole broke into two pieces when it struck a steep hill approximately 200 m from a minor public road, but clear of any built-up areas and third parties. There was no damage to the helicopter or lifting equipment. The operator considered the most probable cause for the inadvertent release of the load was that the sling, which was carrying the load, was not positioned correctly in the helicopter's hook which was of the spring-loaded keeper design. As a result of this incident, the operator is continuing to phase out the use of this design of hook for most of its operations and has changed its procedures so that only the operator's employees are permitted to load the hook when spring-loaded keeper hooks are used.

History of the flight

G-PDGF was being used to transport wooden poles from a storage facility to work sites alongside an electricity line which was being refurbished. Forty-seven poles were to be transported over the course of two days. The pilot of G-PDGF met his ground handler, who worked for the same company, and three of the client's employees prior to starting the lifting operation.

The client's employees had previously attended a training course on helicopter operations, which covered lifting underslung loads. The ground handler briefed the employee who would be hooking on the loads at the storage facility. The ground handler's task was to assist and oversee this operation but also to refuel the aircraft at a separate refuel site. This meant that, whilst the ground handler was at the refuelling site, the client's employee would be left unsupervised to 'hook on' the loads.

During the afternoon of day one, after successfully transporting several loads during the morning, G-PDGF arrived to pick up a 700 kg pole whilst the ground handler was away from the storage facility. The pilot manoeuvred the helicopter to allow the client's employee to attach the load to the hook.

The design of the hook (Figure 1) consists of a load bearing beam which, when electrically actuated by the pilot, causes the beam to rotate around a pivot allowing the load to be released before then re-closing. There is a spring-loaded keeper which enables access to place the load across the beam. The beam also features a semi-circular recess where the sling, which is usually used to carry a load, should be positioned.

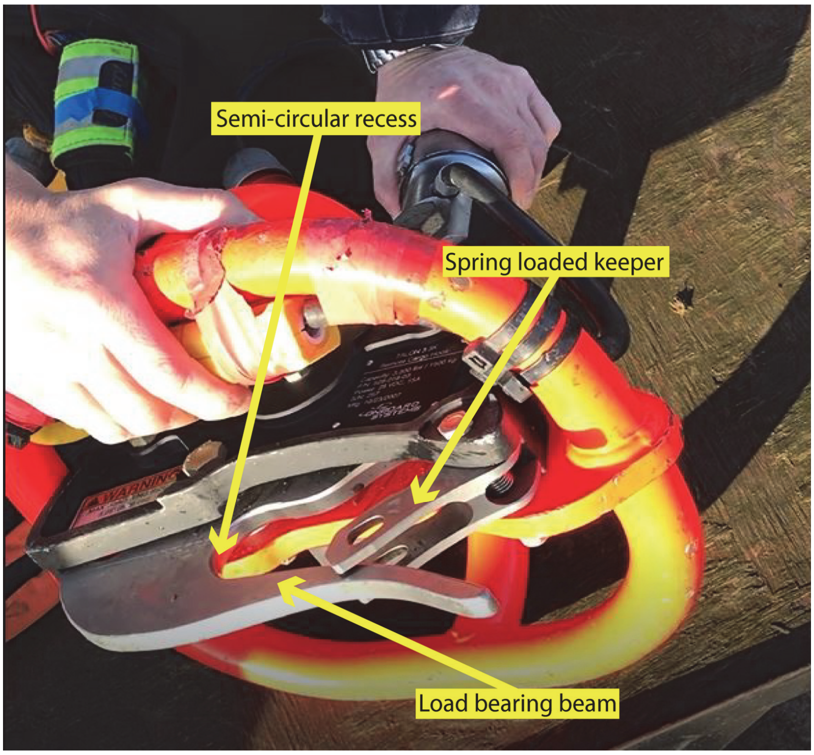

Figure 1
The spring-loaded keeper hook fitted to G-PDGF

Once the load was attached the pilot climbed G-PDGF to lift the pole off the ground. He transitioning to forwards flight whilst, as was his usual practice, cross-referencing the engine instruments and checking the load in a mirror as he increased airspeed in 10 kt increments. He stabilised the helicopter at 60 kt and 200 ft agl, as opposed to his usual transit speed of 80 kt, for the short flight to the work site.

However, after about 6 km the pole began to develop a spinning motion, which rapidly increased in intensity, and which the pilot could feel through the airframe. Immediately, he lowered the collective and applied rear cyclic to bring G-PDGF rapidly to the hover but, before he could complete this manoeuvre, the pole fell from the helicopter. The pole struck the side of a steep hill approximately 200 m from a minor public road, but clear of any built-up areas and third parties. It broke into two pieces. The pilot immediately returned G-PDGF to the refuel site and shutdown. He inspected the undamaged hook, which was found in the closed position, and the strop that was later recovered from the hillside was also undamaged.

Analysis

The operator's assessment of the incident considered four causes for the inadvertent release of the load: the inadvertent release of the electrically-operated hook by the pilot; the release of the hook due to an electrical malfunction; and two causes, similar in nature, that could cause the spring-loaded keeper to be forced open during flight.

The operator considered the most likely cause was that, when the load was hooked on at the storage facility, the sling carrying the load was not positioned fully into the semi-circular recess on the load bearing beam which normally provides additional protection against any movement of the sling. This would have allowed the sling to move during flight and, as the load spun rapidly, to overcome the resistance of the spring-loaded keeper thereby releasing the load. The operator considered it unlikely that the load was released inadvertently by the experienced pilot because the release system requires two independent switches on the cyclic to be depressed simultaneously to command a release. The hook and its release system were electrically checked by the operator's engineering department and no faults were found; however, an intermittent fault could not be ruled out as an alternative cause for the inadvertent release of the load.

Conclusion

The most probable cause for the inadvertent release of the load was that the load had not been positioned correctly across the hook's load bearing beam when the load was hooked on. At this time, the client's employee, although having been trained in underslung load lifting operations, was working alone and was not being directly supervised. However, an intermittent fault could not be ruled out as an alternative cause for the release.

Safety action

As a result of this incident, the operator is taking the following action:

> The operator is continuing to phase out the use of hooks with spring-loaded keepers in favour of using keeperless hooks for most of its operations. Additionally, the operator has amended its procedures so that, if spring-loaded keeper hooks are used, only the operator's employees will carry out loading operations. The operator advised that, as keeperless hooks require the use of two hands, it will retain a few spring-loaded keeper hooks for tasks such as lifting a load from a scree-covered hillside, where using both hands poses a greater risk to the loader.

AAIB Record-Only Investigations

This section provides details of accidents and incidents which were not subject to a Field or full Correspondence Investigation.

They are wholly, or largely, based on information provided by the aircraft commander at the time of reporting and in some cases additional information from other sources.

The accuracy of the information provided cannot be assured.

Record-only UAS investigations reviewed April - May 2020

17-Dec-19 **DJI Inspire 2** **Lake Vyrnwy, Powys**
The UAS flew a pre-programmed route correctly but the programmed altitude was below the top of some trees along the route. The UAS struck a tree and dropped to the ground.

08-Feb-20 **DJI Mavic 2 Enterprise** **Barnsley, South Yorkshire**
The UAS was being used to monitor a football crowd and was flying over a building site near to a steel structure that was being erected. The operator noticed the UAS battery rapidly deplete to zero charge and the UAS automatically landed, without pilot input, in a carpark.

31-Mar-20 **Vulcan Harrier** **Red Lake, Dartmoor, Devon**
The UAS struck the ground following a programming error.

23-Apr-20 **Sensefly eBee Plus** **Cricklewood, London**
The UAS suffered a sudden loss of data link with the ground station. Despite attempts to reconnect visual contact was lost and the UAS was not recovered.

30-Apr-20 **DJI Phantom 4** **Warrington Cemetery, Merseyside**
The UAS lost GPS lock and, shortly after, the control link. It subsequently flew in a direction away from the operator and was not recovered.

Miscellaneous

This section contains Addenda, Corrections and a list of the ten most recent Aircraft Accident ('Formal') Reports published by the AAIB.

The complete reports can be downloaded from the AAIB website (www.aaib.gov.uk).

BULLETIN CORRECTION

Aircraft Type and Registration:	Boeing 777-200, AP-BGZ
Date & Time (UTC):	22 August 2019 at 1625 hrs
Location:	Birmingham Airport
Information Source:	Aircraft Accident Report Form submitted by the commander

AAIB Bulletin No 5/2020, page 90 refers

When originally published the cover page of this report stated that there were two crew on board the aircraft and 218 passengers, whereas it should have stated that there were 11 crew and 209 passengers. The cover page should also have stated that no crew or passengers were injured during the event.

It should read as follows:

Persons on Board:	Crew - 11	Passengers - 209
Injuries:	Crew - None	Passengers - None

The online version of the report was amended on 11 June 2020.

BULLETIN CORRECTION

Aircraft Type and Registration:	Quik GT 450, G-CFKJ
Date & Time (UTC):	2 December 2019 at 0840 hrs
Location:	Field approx 2 miles north-east of Caernarfon Airport, Gwynedd
Information Source:	Aircraft Accident Report Form submitted by the pilot.

AAIB Bulletin No 5/2020, page 118 refers

The aircraft registration was wrongly stated on two occasions in the penultimate paragraph of the report. It should read:

> The Rotax 912 engine fitted to G-CFKJ relied on hot engine coolant to warm the carburettor body to prevent ice forming. The radiator can be partially covered to ensure that the coolant is maintained at a temperature above 80°C. The maintenance organisation stated that approximately 75% of the radiator area would normally be covered during the winter months to achieve the required temperature; however, on G-CFKJ only 25% of the radiator was covered.

The online version of the report was amended on 11 June 2020.

BULLETIN CORRECTION

Aircraft Type and Registration:	Standard Cirrus 75, G-DDGX
Date & Time (UTC):	27 July 2019 at 1130 hrs
Location:	Gwernesney Airfield, Monmouthshire
Information Source:	AAIB Field Investigation

AAIB Bulletin No 6/2020, page 58 refers

When this report was published the following words '*engaged and the tailplane could be easily dislodged.*' were missed off the end of the first paragraph on page 58. The paragraph should read:

> However, it was possible on G-DDGX to achieve a condition where the locking lever was in the fully forward position and the tapered bolt was only partially engaged in the front fitting (Figure 14). In this condition neither the rear mechanism nor the front fitting were properly engaged and the tailplane could be easily dislodged.

The online version of the report was amended on 28 May 2020.

TEN MOST RECENTLY PUBLISHED FORMAL REPORTS ISSUED BY THE AIR ACCIDENTS INVESTIGATION BRANCH

3/2014 Agusta A109E, G-CRST
Near Vauxhall Bridge,
Central London
on 16 January 2013.

Published September 2014.

1/2015 Airbus A319-131, G-EUOE
London Heathrow Airport
on 24 May 2013.

Published July 2015.

2/2015 Boeing B787-8, ET-AOP
London Heathrow Airport
on 12 July 2013.

Published August 2015.

3/2015 Eurocopter (Deutschland) EC135 T2+, G-SPAO
Glasgow City Centre, Scotland
on 29 November 2013.

Published October 2015.

1/2016 AS332 L2 Super Puma, G-WNSB
on approach to Sumburgh Airport
on 23 August 2013.

Published March 2016.

2/2016 Saab 2000, G-LGNO
approximately 7 nm east of
Sumburgh Airport, Shetland
on 15 December 2014.

Published September 2016.

1/2017 Hawker Hunter T7, G-BXFI
near Shoreham Airport
on 22 August 2015.

Published March 2017.

1/2018 Sikorsky S-92A, G-WNSR
West Franklin wellhead platform,
North Sea
on 28 December 2016.

Published March 2018.

2/2018 Boeing 737-86J, C-FWGH
Belfast International Airport
on 21 July 2017.

Published November 2018.

1/2020 Piper PA-46-310P Malibu, N264DB
22 nm north-north-west of Guernsey
on 21 January 2019.

Published March 2020.

Unabridged versions of all AAIB Formal Reports, published back to and including 1971, are available in full on the AAIB Website

http://www.aaib.gov.uk

GLOSSARY OF ABBREVIATIONS

aal	above airfield level
ACAS	Airborne Collision Avoidance System
ACARS	Automatic Communications And Reporting System
ADF	Automatic Direction Finding equipment
AFIS(O)	Aerodrome Flight Information Service (Officer)
agl	above ground level
AIC	Aeronautical Information Circular
amsl	above mean sea level
AOM	Aerodrome Operating Minima
APU	Auxiliary Power Unit
ASI	airspeed indicator
ATC(C)(O)	Air Traffic Control (Centre)(Officer)
ATIS	Automatic Terminal Information Service
ATPL	Airline Transport Pilot's Licence
BMAA	British Microlight Aircraft Association
BGA	British Gliding Association
BBAC	British Balloon and Airship Club
BHPA	British Hang Gliding & Paragliding Association
CAA	Civil Aviation Authority
CAVOK	Ceiling And Visibility OK (for VFR flight)
CAS	calibrated airspeed
cc	cubic centimetres
CG	Centre of Gravity
cm	centimetre(s)
CPL	Commercial Pilot's Licence
°C,F,M,T	Celsius, Fahrenheit, magnetic, true
CVR	Cockpit Voice Recorder
DFDR	Digital Flight Data Recorder
DME	Distance Measuring Equipment
EAS	equivalent airspeed
EASA	European Aviation Safety Agency
ECAM	Electronic Centralised Aircraft Monitoring
EGPWS	Enhanced GPWS
EGT	Exhaust Gas Temperature
EICAS	Engine Indication and Crew Alerting System
EPR	Engine Pressure Ratio
ETA	Estimated Time of Arrival
ETD	Estimated Time of Departure
FAA	Federal Aviation Administration (USA)
FIR	Flight Information Region
FL	Flight Level
ft	feet
ft/min	feet per minute
g	acceleration due to Earth's gravity
GPS	Global Positioning System
GPWS	Ground Proximity Warning System
hrs	hours (clock time as in 1200 hrs)
HP	high pressure
hPa	hectopascal (equivalent unit to mb)
IAS	indicated airspeed
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
IP	Intermediate Pressure
IR	Instrument Rating
ISA	International Standard Atmosphere
kg	kilogram(s)
KCAS	knots calibrated airspeed
KIAS	knots indicated airspeed
KTAS	knots true airspeed
km	kilometre(s)
kt	knot(s)
lb	pound(s)
LP	low pressure
LAA	Light Aircraft Association
LDA	Landing Distance Available
LPC	Licence Proficiency Check
m	metre(s)
mb	millibar(s)
MDA	Minimum Descent Altitude
METAR	a timed aerodrome meteorological report
min	minutes
mm	millimetre(s)
mph	miles per hour
MTWA	Maximum Total Weight Authorised
N	Newtons
N_R	Main rotor rotation speed (rotorcraft)
N_g	Gas generator rotation speed (rotorcraft)
N_1	engine fan or LP compressor speed
NDB	Non-Directional radio Beacon
nm	nautical mile(s)
NOTAM	Notice to Airmen
OAT	Outside Air Temperature
OPC	Operator Proficiency Check
PAPI	Precision Approach Path Indicator
PF	Pilot Flying
PIC	Pilot in Command
PM	Pilot Monitoring
POH	Pilot's Operating Handbook
PPL	Private Pilot's Licence
psi	pounds per square inch
QFE	altimeter pressure setting to indicate height above aerodrome
QNH	altimeter pressure setting to indicate elevation amsl
RA	Resolution Advisory
RFFS	Rescue and Fire Fighting Service
rpm	revolutions per minute
RTF	radiotelephony
RVR	Runway Visual Range
SAR	Search and Rescue
SB	Service Bulletin
SSR	Secondary Surveillance Radar
TA	Traffic Advisory
TAF	Terminal Aerodrome Forecast
TAS	true airspeed
TAWS	Terrain Awareness and Warning System
TCAS	Traffic Collision Avoidance System
TODA	Takeoff Distance Available
UA	Unmanned Aircraft
UAS	Unmanned Aircraft System
USG	US gallons
UTC	Co-ordinated Universal Time (GMT)
V	Volt(s)
V_1	Takeoff decision speed
V_2	Takeoff safety speed
V_R	Rotation speed
V_{REF}	Reference airspeed (approach)
V_{NE}	Never Exceed airspeed
VASI	Visual Approach Slope Indicator
VFR	Visual Flight Rules
VHF	Very High Frequency
VMC	Visual Meteorological Conditions
VOR	VHF Omnidirectional radio Range

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