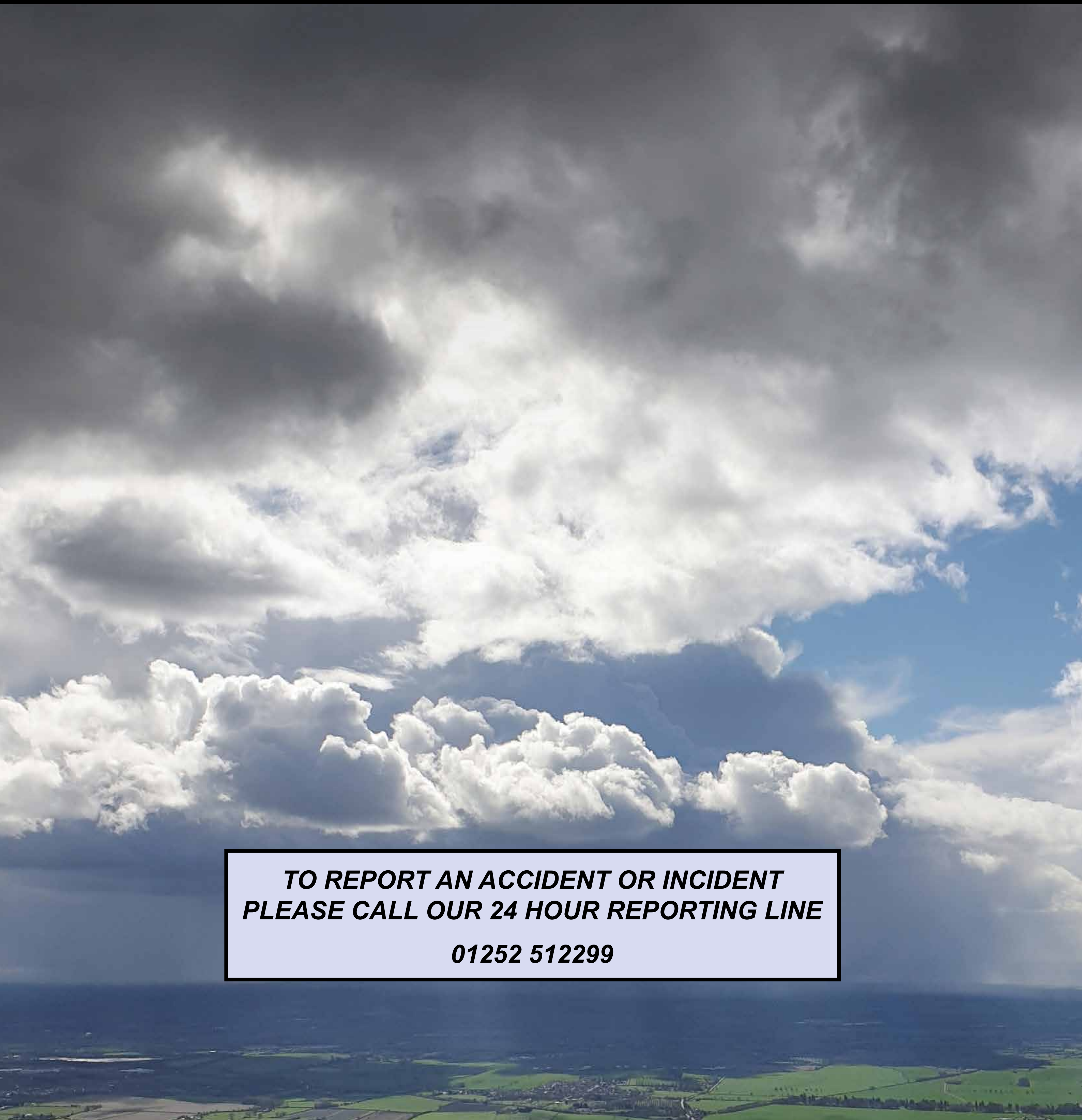
AAIB
Air Accidents Investigation Branch

AAIB Bulletin 3/2021



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The sole objective of the investigation of an accident or incident under these Regulations is the prevention of future accidents and incidents. It is not the purpose of such an investigation to apportion blame or liability.

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This bulletin contains facts which have been determined up to the time of compilation.

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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:	1) Boeing 737-8AS, EI-DPC 2) Boeing 737-8Z9, G-GDFR 3) Boeing 757-28A, G-OOBA
No & Type of Engines:	1) 2 CFM56-7B27 turbofan engines 2) 2 CFM56-7B26 turbofan engines 3) 2 Rolls-Royce RB211-535E4-37 turbofan engines
Year of Manufacture:	1) 2006 (Serial no: 33604) 2) 2003 (Serial no: 30421) 3) 2000 (Serial no: 32446)
Date & Time (UTC):	8 September 2020 at 2227 hrs
Location:	Birmingham Airport
Type of Flight:	1) Commercial Air Transport (Passenger) 2) Commercial Air Transport (Passenger) 3) Commercial Air Transport (Passenger)
Persons on Board:	1) Crew - 6 Passengers - 35 2) Crew - 6 Passengers - 181 3) Crew - 8 Passengers - 190
Injuries:	1) Crew - None Passengers - None 2) Crew - None Passengers - None 3) Crew - None Passengers - None
Nature of Damage:	1) None reported 2) None reported 3) None reported
Commander's Licence:	1) Airline Transport Pilot's Licence 2) Airline Transport Pilot's Licence 3) Airline Transport Pilot's Licence
Commander's Age:	1) N/A 2) N/A 3) N/A
Commander's Flying Experience:	1) N/A 2) N/A 3) N/A
Information Source:	AAIB Field Investigation

Synopsis

After completing some routine maintenance on the approach lights to Runway 33 at Birmingham Airport, two airport engineering services technicians drove along the runway in an airport works pickup truck en route to their next task. In the back of the pickup truck was a step ladder that they had been using. As they drove through the touch down zone, the ladder came out of the vehicle and came to rest just to the right of the runway centreline. Three aircraft subsequently landed on Runway 33. The first two aircraft reported that they

might have seen something on the runway during landing but could not be certain that it was not paint markings. Having been informed of the reports of the two preceding aircraft, the third aircraft elected to land, following which the flight crew notified ATC that they had seen a ladder on the runway. The ladder had been on the runway for 37 minutes before it was retrieved by the airport safety team.

The airport completed an investigation into the events and have taken a number of safety actions intended to prevent reoccurrence. The CAA issued a SkyWise notification under Aerodrome Safety Alerts to raise awareness of this event amongst airside workers.

History of the flights

Birmingham Airport had four scheduled arrivals after 2200 hrs on the night of the incident. Three of the arrivals were radar vectored to land on Runway 33 with a separation of 4 nm between each aircraft.

The first aircraft (EI-DPC) landed at 2225 hrs. Two minutes later the second aircraft (G-GDFR) landed and on vacating the runway the crew advised ATC that they may have seen something in the touch down zone. They were not sure if it was an object of some sort or a paint marking on the runway. The crew from EI-DPC then commented that they may have also possibly seen something just after the touch down markers. The tower controller contacted the third aircraft (G-OOBA) on the final approach and asked if they were happy to continue given the report from the two previous aircraft. The crew elected to continue and landed at 2229 hrs. As the aircraft slowed to vacate the runway, the crew informed ATC that there was an object in the touch down zone, just to the right of the centreline, possibly a ladder.

ATC ordered a runway inspection, which found a 7 ft A-frame step ladder on the runway.

This was subsequently established to have fallen from a pickup truck referred to as Works Vehicle 4 (WV4) as it had travelled along the runway after technicians had completed earlier maintenance on the approach lights to Runway 33. Figure 1 shows a view looking up Runway 33 with the ladder on the runway.

The runway was immediately closed. A full inspection was carried out before re-opening after 19 minutes as nothing else was found. The fourth arriving aircraft was 50 nm behind the three previous aircraft and was given an arrival hold until the runway reopened. This aircraft landed at 2254 hrs.

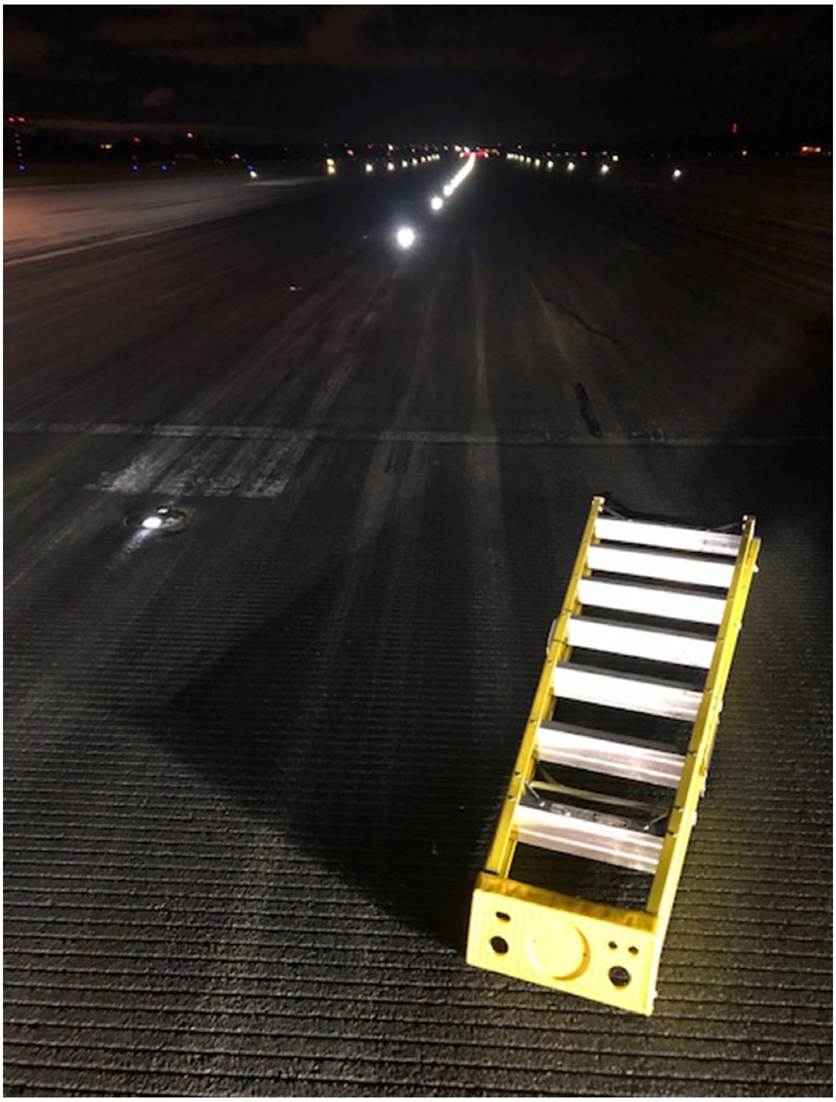

Figure 1
View up Runway 33 with the ladder in the approximate position it was found

Airfield information

Birmingham Airport has a single runway orientated 15/33. The runway has a grooved asphalt surface. The runway is also fitted with supplementary lights within the touchdown zone for low visibility operations. The passenger terminal and airport services are located on the east side of the runway. The west side of the runway is used by private flight companies, cargo operations and a police helicopter. The ATC tower is located on the west side of the runway. Figure 2 shows the layout of the airport and Figure 3 shows a magnified view with details of the locations referred to in this report.

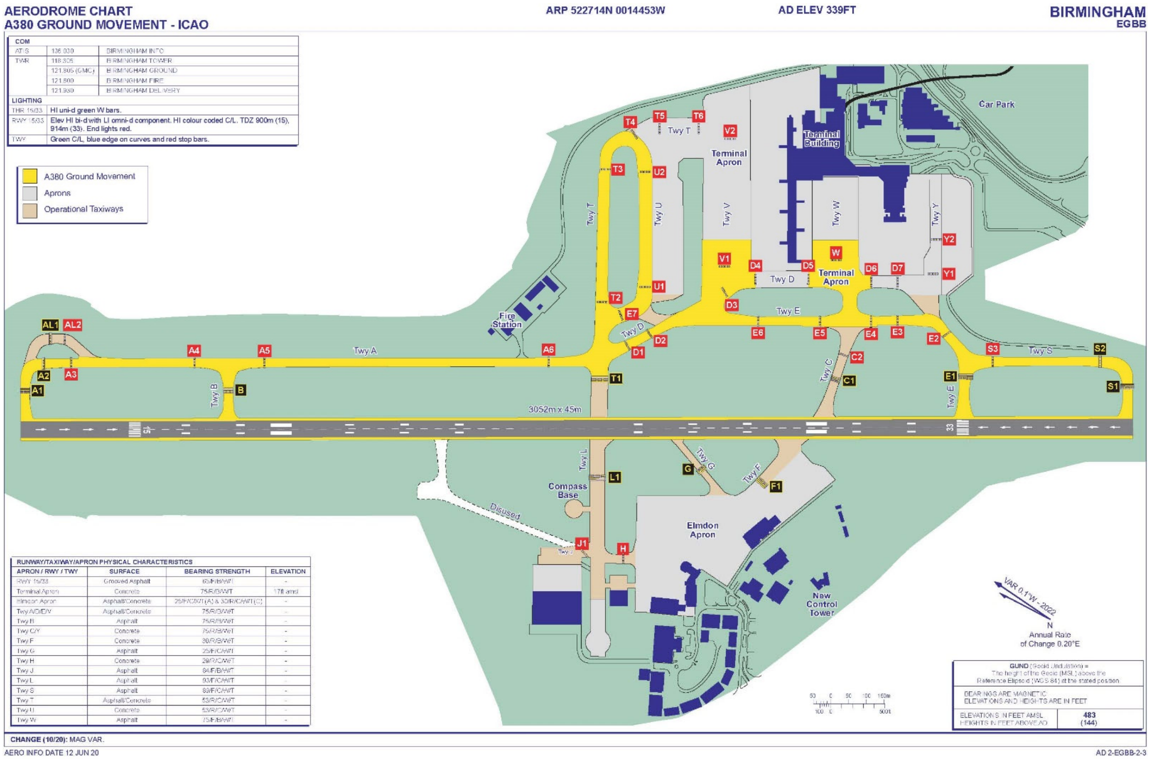

Figure 2

Layout of Birmingham Airport

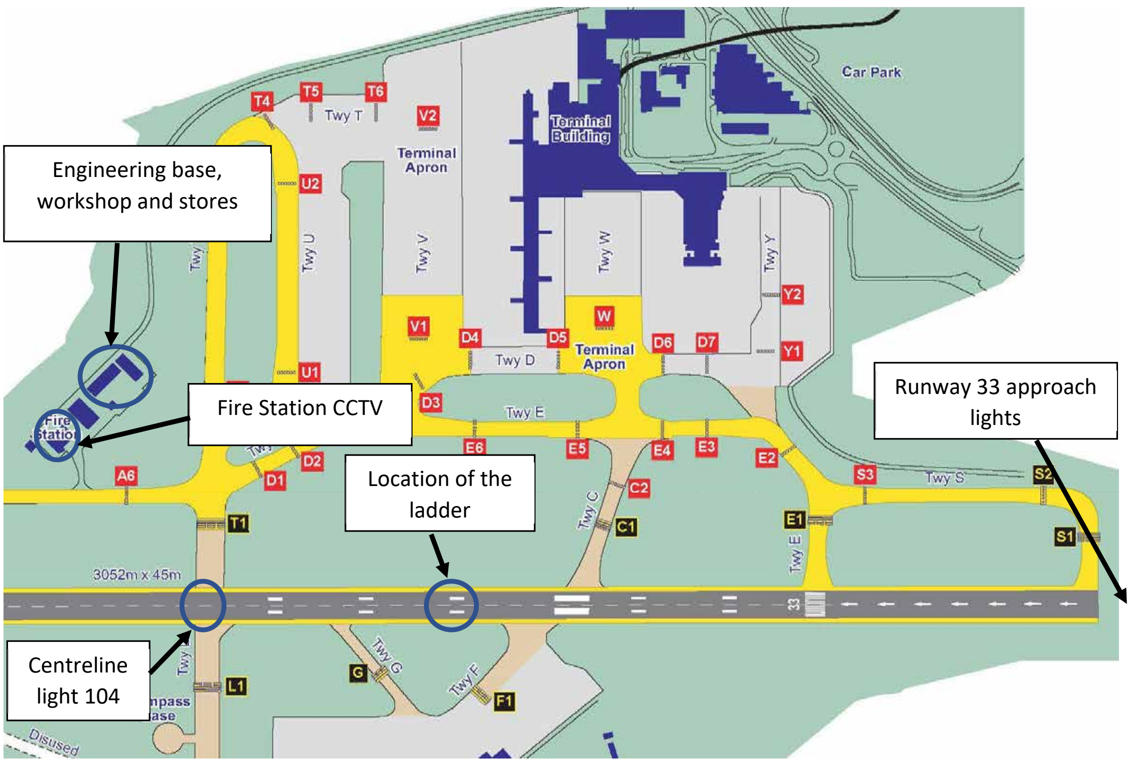

Figure 3

Magnified view of the airport

The last runway inspection was completed at 2128 hrs with nothing found on the runway. The last aircraft movement before the three subsequent landings was a departure from Runway 15 at 2135 hrs.

The airport has surface movement radar (SMR) and all the airfield vehicles were fitted with transponders that identify the vehicle and its position on the SMR display in the ATC tower. The SMR at Birmingham is not designed to detect foreign object debris (FOD).

Airfield working

Engineering services are responsible for the maintenance of most of the airport facilities including the terminal buildings, baggage system and airfield lighting. Several teams worked at the airport at any one time completing routine maintenance, fixing reported faults and testing of the systems. Each team consisted of at least two members.

Driver training

The airport operator reported that as part of its airside driver permit training package, a presentation was delivered to all movement[1] area drivers that included the requirement to ensure that all loads were secure before undertaking journeys. It also reminded drivers of their responsibilities to ensure vehicles were in a safe condition prior to use. Whilst there was no specific emphasis on FOD prevention during airside driver training, the airport had standing instructions on load security and FOD applicable to all airside area drivers.

Equipment

Available vehicles

The engineering services staff had several work vehicles available and authorised for use on the airfield. These vehicles, referred to as Works Vehicles (WV), consisted of the following.

- WV3 was a large long wheelbase van fitted out inside as a mobile workshop. It contained tools, spares and equipment suitable for most tasks undertaken by the ground engineering staff. It was equipped with two-way radio communication and external work spotlights mounted on the left side of the roof. Although WV3 was well equipped for the majority of airfield tasks its reliability was a cause for concern amongst the staff.

- WV4, the vehicle from which the ladder fell, was an all-wheel drive crew cab pickup truck with an open load bay and latched tail gate. The load bay was fitted with a rigid black plastic liner and there were two fixed cargo restraint rings attached towards the front and rear of the load side panels. The vehicle was also fitted with two-way radio communication and external work spotlights mounted on a roof rail on the left side.

Footnote

[1] That part of an aerodrome intended for the surface movement of aircraft including the manoeuvring area, aprons and any part of the aerodrome provided for the maintenance of aircraft.

- WV10 was a large crew cab panel van with a plywood lined cargo bay. It was fitted with two-way radio communication but was not fitted with external work spot lighting. This vehicle was primarily used as a backup vehicle but was reported by the technicians as not being popular because of the difficulty in restraining equipment and tools in the rear load bay.

The technicians chose to use WV4 as they were concerned about the reliability of WV3 for working on the runway, and the security of equipment on WV10.

Tools, maintenance equipment and spares

The engineering services staff operated from a self-contained set of buildings on the northerly side of the airport near to the fire station and airfield operations complex (Figure 3). They consisted of administrative offices and crew rooms alongside workshops and storage units. The vehicles were readily accessible in a yard close by.

There were several storage areas within the units which were fitted out with heavy duty steel shelving. These held a variety of spares to support the airport infrastructure within domestic buildings and the airport outside lighting, guidance systems and signage. Some larger tools were also kept on the shelves alongside the spares. Spares and equipment were selected and replenished by the staff on an as-required basis. There was no formal spares and equipment withdrawal or location log, and staff advised that they generally knew what was available and where items were kept.

Ladder found on runway

The ladder was of a lightweight A-frame of fibreglass and aluminium construction, was 2.2 m high and had 7 steps. It was painted bright yellow and there was a polypropylene combined step and hinge plate at the top of the ladder. It had been designed for ease of handling and could be set up and positioned by one person. The ladder was in good working condition.

Ladder restraint used in WV4

An elastic bungee was used to restrain the ladder in the vehicle. It was approximately 80 cm long and 10 mm in diameter with woven sheathing around its elastic strands. It was fitted with a plastic covered open-steel wire hook at each end. The diameter of the wire used to form the hook is approximately 2 mm to 3 mm. The bungee could be stretched approximately 1.25 times its own length and this was limited by the sheathing at which point it became rope like.

The bungee was taken from an understair storage cupboard in the main workshop storage unit.

In preparation for the work on the approach light the stepladder was put into the load bay of WV4 and the elastic bungee strap used to secure it in place. Figures 4 and 5 show how the ladder was positioned and held in the load bay.

Figure 4
Ladder loaded onto WV4

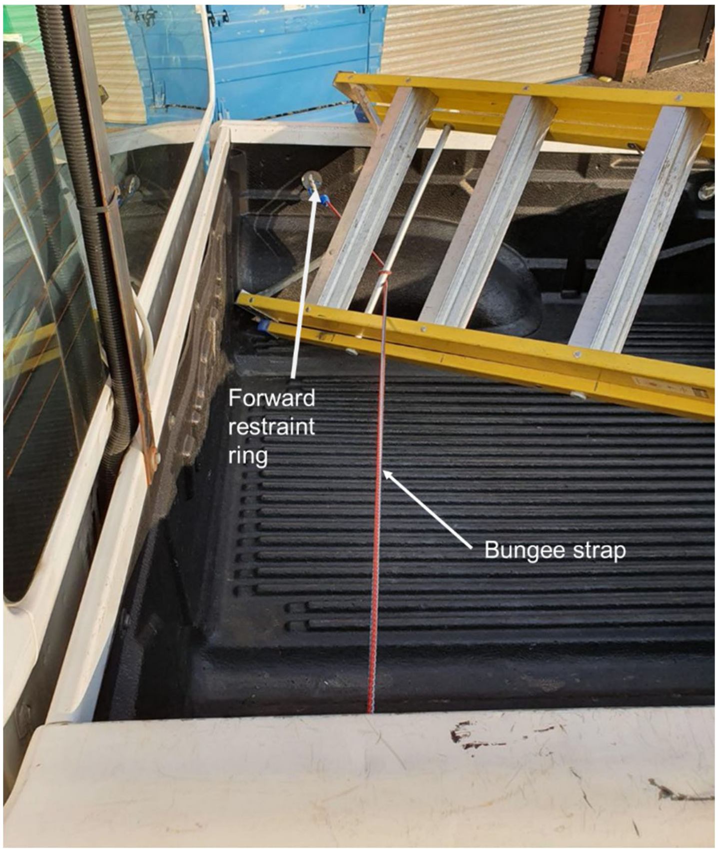

Figure 5
Ladder restraint method in WV4
(Picture taken after the event and reconstructed by one of the technicians)

The bungee prompted some discussion after the event. The items in the understair storage cupboard appeared to be stored haphazardly and contained a selection of smaller items related to airfield maintenance and domestic equipment. Senior members of the engineering staff did not consider the bungee a normal part of their equipment and were not clear on its providence. However, they were able to show more suitable ratchet straps, although it took a short while to locate them on one of the equipment shelves in another storage area.

During examination of WV4 and the ladder, a safer method of carrying the ladder was demonstrated. The ladder was placed upright in the load area angled forward, leaning against a vertical frame attached to the roof bars with its feet against the base of the tailgate. The frame was ideally placed to fix the ladder in place with a ratchet strap.

Damage to equipment

The ladder was recovered from the runway by the airport operations staff. Later examination of the ladder found minor scuff damage on the corner edges of the combined step and hinge plate. A small amount of material towards the edge of the scuff marks had been frayed and discoloured with a grey-black appearance (Figure 6). The bungee was examined, and this was in good condition except for the opening out of one of its hooks (Figure 7).

Figure 6
Scuff damage to the top of the ladder

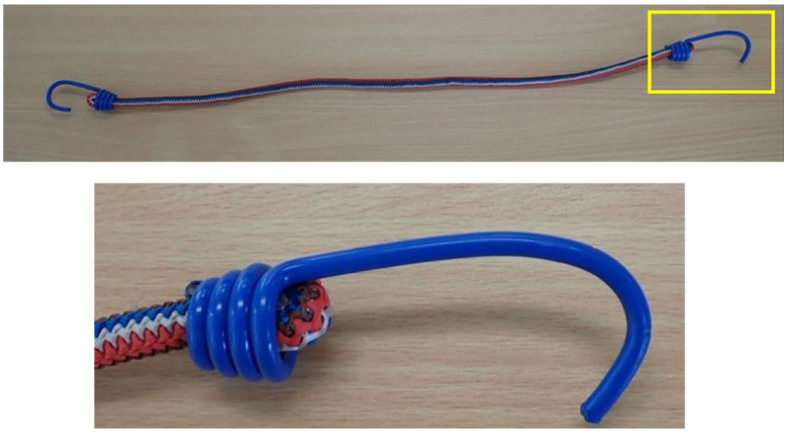

Figure 7
Bungee strap and damage to hook

Personnel – technicians

On the night of the incident, a team of two technicians were working airside and responsible for the airfield lighting. Both technicians were qualified electricians. They had been working together as a team for less than a month. They were on their second of two nightshifts after two days off and were scheduled to be off for the next two days.

Whilst working as a pair on airfield lighting, especially on the runway or taxiways, it was standard practice for one technician to remain in the vehicle whilst the other technician completed the work. This meant that if the runway or taxiway was needed by ATC, then the vehicle could be readily moved.

Technician 1

Technician 1 had been working at the airport for ten months. He had some limited previous experience in the aviation sector as an electrician at a manufacturing plant, but this was his first job working on an airport. He had been supervised by more experienced technicians during his training. During the period related to the incident, Technician 1 was driving the vehicle.

Technician 2

Technician 2 had been working at the airport for 18 months. He previously worked as a technician in an automated plant in the logistics industry, but he had been given training for his role at the airport. During the period related to the incident, Technician 2 was performing the work outside of the vehicle.

Order of work for the technicians

When the technicians arrived for their shift there was a list of items for them to complete during the night if there was sufficient time available. This included some routine maintenance tasks on the Runway 33 approach lights and some of the centreline lights. They also needed to complete a check of all the runway lights in both directions. Technician 2 went out to complete a small job whilst Technician 1 remained at the engineering base. When Technician 2 returned, he rang ATC to ask when it might be possible to access the runway to perform the all lights check, work on the approach lights and the centreline lights task. He was informed that there would be a gap of around an hour beginning at 2130 hrs. The two technicians then began to prepare their equipment for the tasks and to load the WV4 which they had selected.

Technician 2 loaded the ladder, which would be required to access the approach lights, into the back of WV4. Having collected all their equipment, they set off for the runway with Technician 1 driving and Technician 2 in the front passenger seat. The routing from the engineering base to the runway required the vehicle to pass in front of the airfield fire station. The front of the fire station had a CCTV camera fitted (Figure 8). Although it was dark, the camera did capture the vehicle each time it passed. WV4 was seen passing the fire station at 2133 hrs.

Figure 8

WV4 passing the fire station at 2133 hrs

At 2135 hrs WV4, having gained permission from ATC, entered Runway 33 from holding point S1. The vehicle then parked at the edge of the grass in the undershoot of the runway. Figure 9 shows part of the SMR picture with WV4 (highlighted) parked at the beginning of Runway 33.

Figure 9

WV4 at the beginning of Runway 33

Once the vehicle was parked, Technician 2 got out of the vehicle, took the ladder from the back and proceeded down to the approach lights. Technician 1 remained in the vehicle. The maintenance work took approximately 15 minutes and upon returning to WV4, Technician 2 stated he secured the ladder in the back using the bungee, before returning to the passenger seat. WV4 then proceeded along the runway whilst the technicians checked the lights. This involved inspecting the centreline lights, edge lights and the supplementary lights in the touch down zone. This was the only time from when they left the engineering base at 2133 hrs to begin the work on the approach lights that they passed the point on the runway where the ladder was subsequently found; WV4 was calculated to be travelling at about 45 mph at the time when the ladder fell from the vehicle. Figure 10 shows the point at which they passed that point on the runway. The time was 2154 hrs.

Figure 10

WV4 at the location where the ladder was found

Having driven to the end of Runway 33, WV4 was then turned around and headed for the first centreline light they were to attend to, which was number 104 (see Figure 3). The scheduled maintenance requirements for the centreline lights was to check the torque on the bolts holding the lights in position. To do this the technicians had a wireless Bluetooth-equipped electronic torque wrench. This indicated to the technician doing the work when the correct torque was applied, and also transmitted the data to a mobile device which recorded the date and time of the work. When they reached centreline light 104, Technician 2 again got out the vehicle to complete the work. When he attempted to wirelessly connect the torque wrench with the mobile device, he found it would not do so and they therefore had to return to the engineering base in order to get it to work as required. WV4 vacated the runway at 2159 hrs. To drive to the engineering base, WV4 passed the front of the fire station and was captured on CCTV. Figure 11 is a CCTV image of WV4 with the tailgate of the truck up, but the ladder not present.

Figure 11

CCTV of WV4 returning to the engineering base at 2159 hrs

When WV4 reached the engineering base, Technician 2 exited the vehicle and proceeded inside to get the torque wrench and mobile device to communicate. Technician 1 remained in the driver's seat waiting for his colleague. At 2204 hrs they passed the front of the fire station en route to continue the maintenance on the runway centreline lights.

WV4 asked for and received ATC permission to enter Runway 33 from holding point T1. They proceeded to centreline light 104 and began to work their way towards the end of the runway from centreline light to centreline light. Again Technician 2 was completing the work whilst Technician 1 was driving the vehicle to the right of the centreline in support of his colleague. The vehicle exterior side spotlights were illuminating the work area for Technician 2.

At 2218 hrs Technician 1 was informed by ATC that the first inbound aircraft was 20 nm from touchdown. This was acknowledged by Technician 1, and Technician 2 got back into the vehicle before they vacated the runway via Taxiway B. The vehicle again passed the fire station at 2220 hrs as shown at Figure 12. Note, the tailgate of the truck is up, and the ladder is not present.

Figure 12

WV4 passing the fire station at 2220 hrs

The technicians returned to the engineering base and went inside with the aim of establishing when there might be another gap in aircraft movements to enable them to complete their checks on the runway centreline lights. Having established that there would be a gap after the next landing aircraft, they proceeded back to WV4 ready to go out to the runway. As they approached the vehicle, they realised that the ladder was missing. This was at approximately 2230 hrs.

The technicians first thought was that the ladder had been borrowed and proceeded to drive to where they thought the person who might have the ladder was working. They found that the person was not working that night and, before they could do anything else, they received a call from the Airfield Duty Manager regarding the ladder that had been found on the runway. Neither technician could explain how the ladder had come out of WV4 and neither had seen or heard anything during their journey from the approach lights to centreline light 104.

When the second aircraft to land reported the presence of something in the touch down zone, ATC requested that an Airfield Safety Unit (ASU) vehicle be prepared to perform a runway inspection. This vehicle was cleared onto the runway immediately behind G-OOBA once it had touched down. The ASU vehicle located the ladder at 2231 hrs. The runway was immediately closed and remained so until after a full runway inspection had been carried out. The runway reopened at 2250 hrs.

The ladder had been on the runway for 37 minutes.

Incident site

Figure 1 shows the position of the ladder as found on the runway. The ladder was removed from the runway by the ASU personnel before being collected by the technicians. The ladder was positioned to the right of the centreline of the runway in use (Runway 33) laying almost parallel with the centreline. It was lying beside touch down zone markings which are 550 m from the runway threshold and 150 m beyond the aiming point markings.

The first two aircraft that landed whilst the ladder was on the runway were Boeing 737-800 (B737). The third aircraft was a Boeing 757-200 (B757). There was no evidence that any of the aircraft had contacted the ladder whilst it was on the runway. The B737 has a smaller distance between its nosewheels and mainwheels. Assuming that the aircraft all landed with their nosewheels astride the centreline of the runway, and using landing gear dimensional data from the B737, this means the ladder was between 0.2 m and 2.29 m from that line.

With landing speeds in excess of 120 kt, an aircraft hitting an object such as the ladder may have resulted in substantial damage. In this case, taking the position of the ladder on the runway into account, and the main and nose landing gear track width, all three aircraft narrowly missed the ladder.

ATC

The *'Manual of Air Traffic Services'* (MATS) contains procedures, instructions and information which form the basis of Air Traffic Services (ATS) within the UK. The manual is divided into two parts. Part 1 contains instructions that apply to all Air Traffic Service Units (ATSU) within the UK, whilst Part 2 contains instructions for a specific ATSU. Part 1 is produced and published by the UK CAA as CAP 493, with Part 2 being produced by the ATSU and approved by the CAA.

MATS Part 1

MATS Part 1 contains no guidance on the frequency of runway inspections. Generally, ATC are not responsible for runway inspections unless specifically nominated. Due to the variations in movement rates, environmental considerations and local conditions responsibility for the setting of policies on runway inspections is delegated to the individual airport operator. The arrangements will be detailed in MATS Part 2.

MATS Part 1 does specify that:

> *'Following any incident, or suspected incident, on a runway involving tyre failure, aircraft structural failure or, in the case of turbine-engined aircraft, engine malfunction, the runway is to be inspected before any other aircraft are allowed to use it.'*

This is the only time a runway inspection is required under MATS Part 1.

MATS Part 2

Birmingham MATS Part 2 valid at the time of the incident was issued on the 1 April 2020. In Section 3, Chapter 3 it contains details of the runway inspection procedures to be used. Runway inspections are the responsibility of the ASU. The manual states that there are to be at least four full runway inspections to be carried out within a 24-hour period. It also states:

> *'A Full Runway Inspection should be undertaken prior to a fixed wing aircraft movement if there hasn't been a fixed wing aircraft movement in the previous 30 minutes.'*

Although MATS Part 2 had not been amended, the ASU had amended this procedure via a Local Operating Procedures notice. This extended the period between aircraft movements to an hour before an inspection was required. This procedural change occurred in 2016 but had not been communicated to ATC and as a result MATS Part 2 had not been amended. It could not be established why this was changed.

Other runway inspections are detailed in MATS Part 2 including foreign object debris (FOD)/ bird inspections, inspections following towed aircraft crossing the runway and special runway inspection procedures (SRIP). This special procedure exists for unusual situations such as when FOD is reported on the runway. The procedure is initiated by ATC. Should a SRIP be requested, no further departures are permitted nor any approaches except aircraft that are inside 4 nm from touchdown until the inspection has been completed. For aircraft inside 4 nm, the controller must ask:

> *'Request your intentions?'*

The question is deliberately open in order not to influence the crew in their decision. In the case of G-OOBA the controller actually asked the crew:

> *"Are you happy to continue"*

To which the crew answered that they were and continued to land on Runway 33.

The visual control tower has a view of the whole manoeuvring area of the airport. At night this view is restricted simply because large parts of the airport, including the runway, are not illuminated by overhead lighting. Figure 13 shows the view from the visual control tower at night. It is clear from the picture that it was not possible for the tower controller to either see the ladder coming off WV4 or to spot it laying on the runway. The approximate area where the ladder was found is highlighted.

Figure 13

View from the visual control tower at night with the approximate area where the ladder was found highlighted

Other information

The CAA provided the investigation with data from the Mandatory Occurrence Reporting (MOR) system. A search of this database for MORs relating to FOD on the runway at UK airports showed only one other event where a ladder was found on a runway. The airport investigation into this concluded that these steps were dropped from a departing aircraft. Other large items found in the runway environs included a pallet and a hay bale from grass cutting. No aircraft damage was reported from any of these large items. The database did show numerous occasions when items from airside engineering and operations were dropped or left on the runways or taxiways, but these were small items such as screwdrivers, wrenches, mobile phones and handheld radios.

The majority of reports were of findings of items either from aircraft or the runway itself. The list also included regular reports of bird and wildlife strikes resulting in the finding of carcases.

The AAIB did investigate a landing aircraft hitting an aircraft towbar which had been dropped on a runway in 2019[2].

Analysis

Following maintenance on approach lights, a ladder had been positioned into WV4 but subsequently fell from the vehicle onto the runway and was not detected for some time. In the intervening period three aircraft landed on the runway.

Footnote

2 https://www.gov.uk/aaib-reports/aaib-investigation-to-emb-145ep-g-sajk-and-cessna-p210n-g-cdmh (Accessed 29 January 2021)

Taking the position of the ladder on the runway into account, and the main and nose landing gear track width of all three aircraft, each narrowly missed the ladder. Had the ladder been struck by the main or nose landing gear directly on touchdown, it is likely this would cause the break-up of the ladder with a high risk of explosive tyre burst. This would probably have resulted in high energy fragments hitting the aircraft, thus damaging the airframe or exposed vulnerable hydraulic and electrical components in the landing gear bays. A nose landing gear impact would introduce the additional risk of a nose gear collapse and the ingestion of debris into an engine.

Vehicle selection

There were two reasons why the technicians selected WV4 rather than the apparently more suitable WV3 and WV10. Firstly, reliability was a cause for concern amongst the staff with WV3. Secondly, the inconvenience of tools and equipment falling out of WV10 when its doors were opened. WV4 would have been suitable providing the ladder had been held in the rear of the vehicle securely. However, this depended on how the ladder was positioned and secured in the load area. The choice of restraint was therefore significant.

Choice and method of ladder restraint

At first sight the bungee may have seemed suitable to secure the ladder in WV4. However, when the actual method used was demonstrated, it could be seen why the bungee was unsuitable. The bungee had been stretched almost to its limits around a strut on the ladder and hooked to the right and left forward fixed rings in the load bay side panels (Figure 5). When the vehicle is stationary or moving slowly the method used would keep the ladder in place. Any gentle acceleration or moderate cornering would cause the ladder to move, and the remaining elasticity in the bungee would have provided sufficient restraint.

It is likely that as WV4 accelerated, having passed the aiming point markings, the ladder was caused to moved more rapidly, and its inertia resulted in a ‘snatch’ load on the bungee when it reached the limit of elasticity. At this point, the snatch load would have been transferred into the wire hooks fitted to the ends of the bungee. In this case one of the hooks opened out (Figure 7) making it less effective in the restraint ring. As a result it most likely unhooked, rapidly sprang back, and unravelled itself from the ladder strut. This left the now unrestrained ladder to topple rearwards from WV4. As it fell out and contacted the runway it slid a short distance before coming to a stop causing the abrasion to the edges of the plastic at the top of the ladder (Figure 6).

Given the grooved surface of the runway, the noise of the tyres, especially at speed, would have likely masked any sound made by the ladder as it left the truck. Both technicians were also concentrating on checking the runway lights ahead of the vehicle and therefore their attention would not have been focused on monitoring the ladder.

Radio communications

After the landing of the first aircraft (EI-DPC) no comment was made by the crew regarding anything they may have seen in the touch down zone. After the second aircraft (G-GDFR) taxied off the runway the crew commented that they thought they had seen something and described it as an object or paint. This prompted the crew of the first aircraft to comment that they may also have seen something although they did not give any detail about what they thought they had seen.

Given the comments of the first two aircraft it seems likely that both the controller and the crew of G-OOBA did not believe the item to be of significance. In fact, the overriding impression seemed to be that it was just paint or a marking on the runway.

As G-OOBA was within 4 nm of the threshold, Birmingham MATS Part 2 allowed the controller discretion to permit the aircraft to continue as long as the crew wished to do so. The wording given in the manual was deliberately open to prevent any confirmation bias within the operating crew. The crew of G-OOBA commented that the use of the phrase ‘are you happy to continue’ re-enforced the impression that there was nothing to be concerned about. This impression, together with the belief that it was probably paint, led to the decision of the crew to continue to land on Runway 33.

When faced with having to make a rapid decision about continuing the approach or going around the language used to convey information to the crew is vital. Had the crew of G-OOBA known there was a ladder on the runway they would have chosen to go around. Had the controller known of the ladder the controller would have instructed the crew of G-OOBA to perform a go-around. However, both the crew and the controller can only act on the information they have at the time.

Having been pre-warned to look for something in the touch down zone, the crew of G-OOBA spotted the object and were able to correctly identify it as a ladder. Given where the crew are concentrating their attention during touchdown and the speed of the aircraft at that point, it would have been difficult for the previous crews to identify the item as a foreign object.

Conclusion

The ladder fell from WV4 during the drive along the runway, at the point where it accelerated in the touch down zone after the end of the supplementary lights. The means of securing the ladder in the rear of the open back vehicle using a bungee was not suitable. The bungee was available for use within the maintenance organisation’s facility, but its provenance was not known. More suitable securing equipment was available although not readily to hand.

The airport operator and the CAA have taken several safety actions to prevent reoccurrence.

Safety actions

Airport Operator

In parallel with the AAIB investigation the airport safety staff conducted an investigation and identified several safety actions to reduce the likelihood of this type of event reoccurring. These are summarised under the various headings as follows:

Runway inspections and foreign object debris (FOD)

- Review the airport published procedures regarding runway Inspections
- Review of ATCO immediate actions on receipt of FOD reports.
- Review the airport policy and local operating procedures regarding the FOD monitoring and alerting procedures.
- Define definitive actions to be taken when runway FOD is reported.

Airfield driving

- Undertake review of manoeuvring area and runway (M and R) permit course against the requirements of CAP 790.
- Splitting of the airfield driving permits to authorise M and/or R. This will include R permits issued annually and will include runway incursion awareness training.
- Undertake a review of airfield driving training and permit validity.

Airfield vehicles

- Working Instruction WI-EE-ES-AE-104 issued. Use of WV4. The load area must be kept sterile and clear of materials and tooling to avoid any FOD. Any exceptions to this must be pre-authorised by the Airfield Engineering Supervisor or Senior Airfield Technicians via email. Confirmation should be gained before proceeding with any use.
- Implement an airport vehicle management procedure for all users to include a vehicle FOD inspection procedure.
- Undertake a suitability assessment of all engineering services vehicles used to undertake tasks on the runway and manoeuvring area.

Tool control

- Collaboratively define a common standard of formal tool procedure to be adhered to by all airside users, which includes a tool control safety promotion plan and compliance and audit plan.

Training

- In order to support a Just Culture, identify training to improve knowledge/improving skills of all airside users (all runway users) to include:
  - Define the Birmingham Airport Just Culture
  - Increased task awareness
  - Ensuring data and information is available
  - Encouraging reporting
- Review learnings at safety meetings including; Airside Safety Committee/Local Runway Safety Team/Flight Safety Committee.
- Develop a training plan for the Engineering Services department to include performance objectives, competence checks and approval process.

Civil Aviation Authority (CAA)

The AAIB were concerned that airport ground staff may not have sight of AAIB reports and publications. Therefore, discussions were held with the CAA to explore how this incident might be brought to the attention of the wider aerodrome ground staff community. Accordingly, the CAA issued a SkyWise notification under Aerodrome Safety Alerts section on 16 October 2020 as follows:

> Runway maintenance – equipment control
>
> A recent incident at a UK aerodrome led to maintenance equipment being left on the runway. This incident is currently subject to AAIB investigation.
>
> It has become apparent that a lack of tool control, and security of equipment carried on aerodrome vehicles were contributory factors.
>
> Aerodrome operators should ensure that:
>
> 1. Procedures for both routine maintenance and work in progress includes robust equipment control
> 2. Suitable vehicles are used for transporting equipment
> 3. Equipment is carried in/on vehicles securely
>
> SW2020/230

Published: 25 February 2021.

ACCIDENT

Aircraft Type and Registration:	Alauda Airspeeder Mk II, (UAS, registration n/a)
No & Type of Engines:	4 brushless DC electric motors
Year of Manufacture:	2019
Date & Time (UTC):	4 July 2019 at 1140 hrs
Location:	Goodwood Aerodrome, West Sussex
Type of Flight:	Demonstration flight
Persons on Board:	Crew - None Passengers - None
Injuries:	Crew - N/A Passengers - N/A
Nature of Damage:	Destroyed
Commander's Licence:	Remote Pilot Licence[1]
Commander's Age:	22 years
Commander's Flying Experience:	20 hours (of which 18 were on type) Last 90 days - 3 hours Last 28 days - 1 hour
Information Source:	AAIB Field Investigation

Synopsis

Whilst performing a demonstration flight, the remote pilot lost control of the 95 kg Alauda Airspeeder Mk II scale demonstrator. After the loss of control had been confirmed by the remote pilot, the safety 'kill switch' was operated but had no effect. The Unmanned Aircraft then climbed to approximately 8,000 ft, entering controlled airspace at a holding point for flights arriving at Gatwick Airport, before its battery depleted and it fell to the ground. It crashed in a field of crops approximately 40 m from occupied houses and 700 m outside of its designated operating area. There were no injuries.

The AAIB found that the Alauda Airspeeder Mk II was not designed, built or tested to any recognisable standards and that its design and build quality were of a poor standard. The operator's Operating Safety Case contained several statements that were shown to be untrue.

The Civil Aviation Authority's Unmanned Aircraft Systems (UAS) Unit had assessed the operator's application and, after clarification and amendment of some aspects, issued an exemption to the Air Navigation Order to allow flights in accordance with the operator's Operating Safety Case. The Civil Aviation Authority did not meet the operator or inspect the Alauda Airspeeder Mk II before the accident flight.

Footnote

[1] The pilot's Remote Pilot Licence was issued by the Australian Civil Aviation Safety Authority.

There have been many other similar events where control of an unmanned aircraft has been lost, resulting in either it falling to the ground or flying away. Even a small unmanned aircraft falling from a few metres could cause a fatal injury if it struck a person.

The Civil Aviation Authority and the organisation which designed and operated the Airspeeder Mk II have introduced measures to address a number of issues identified during the course of the investigation. In addition to the actions already taken this investigation report makes 15 Safety Recommendations regarding the operator's procedures, airworthiness standards and the regulatory oversight.

History of the flight

Background information

The Airspeeder Mk II unmanned aircraft (UA) was designed, manufactured and operated by the same company. For simplicity, they will be referred to as the operator.

The operator is an Australian-based designer and manufacturer of 'high performance electric aerial vehicles'[2]. Established in 2016, it has flown what it described as "fully functional" prototypes since early 2017. At the time of the accident the operator's staff consisted of a Chief Executive Officer (CEO), one permanent member of staff and several part-time university students. The operator stated, in their Operating Safety Case (OSC), that they were fully compliant with the pilot and UA licencing and registration requirements of their national regulator, the Civil Aviation Safety Authority (CASA) of Australia and had worked closely with designated CASA representatives since the UA started flying. They also stated that all operations were to be conducted in accordance with the conditions and limitations in their UAS OSC.

Late in 2018, the operator was invited to exhibit the Airspeeder Mk II as part of an exhibition at a large public event at Goodwood House, West Sussex. They were also invited to do some flying demonstrations that were planned to take place at Goodwood Aerodrome and on a golf course adjacent to the exhibition, Figure 2.

The operator arrived in the UK on 28 June 2019 with two Airspeeder Mk II UAs and established a temporary workshop at Goodwood Aerodrome. They conducted an on-site familiarisation and risk assessment and completed pre-flight inspections of the UA as detailed in their OSC.

The CAA issued an exemption to the Air Navigation Order 2016 (ANO) on 3 July 2019, and a test flight was flown at the aerodrome that day using one of the UAs; the CAA were not present for this test flight. This flight resulted in a hard landing due to a loss of power which was later traced to a fault in a battery feeder cable connection. This UA sustained damage to its landing gear. Although required to do so under the regulations, the OSC and the exemption, this accident was not notified to the CAA, CASA, Australian Transport Safety Bureau (ATSB) or AAIB.

Footnote

2 Alauda Racing UAS Operating Safety Case, Volume 1: Operations Manual.

The electronic control box was removed from the damaged airframe and fitted to the remaining UA for a flight the following day.

Accident Flight

The remote pilot stated that on the day of the accident all items in the pre-flight checklist were completed successfully. This included a test of the UA's 'kill switch' which was designed to electrically isolate the power supply to the UA's four motors.

Observing the flight was an audience of around 200 invited guests, the majority of which were positioned on the roof terrace of an adjacent building. Also present were two members of the CAA's UAS Unit who had been involved in assessing the operator's application for the exemption[3].

After takeoff, the remote pilot manoeuvred the UA away from himself and the audience and flew it along Runway 32 before returning in the opposite direction. Just over a minute after takeoff, as the remote pilot was turning the UA close to the threshold of Runway 32, it levelled off. As the remote pilot had not commanded the manoeuvre, he realised that he had lost control of the UA. He immediately informed the maintenance controller, standing next to him and assigned to operate the kill switch, who then attempted to operate the kill switch. This was unsuccessful and the UA was then observed to enter an uncommanded climb.

Figure 1

Airspeeder in flight prior to the accident
(used with permission)

Footnote

3 See section '*CAA on-site*'.

The remote pilot instructed the audience to "take cover", which they did by descending into the building they were on. He also informed the aerodrome's Operations Manager, who was standing close by, that the UA had had a "fly-away" and then the Operations Manager informed the aerodrome's Flight Information Service Officer (FISO) in the tower to advise inbound aircraft to remain clear of the Air Traffic Zone (ATZ). The FISO informed the UK air navigation service provider (NATS) of the potential for the UA to enter the controlled airspace above the aerodrome. The aerodrome's RFFS, who were on standby in their vehicles for the flight, went to assist removing people from the roof of the building. They did not attend the scene in order to maintain the fire cover for aircraft holding outside the ATZ.

The UA continued to climb vertically and drifted in a south-south-westerly direction. After about 4½ minutes it fell, with a high rate of descent, striking the ground in a field of crops. Residents, who saw the UA crash from their garden, approached the accident site to investigate. Upon realising the size of the UA, they called the police.

The remote pilot and the spotters went to the accident site where they carried out their post-crash procedures which included making the battery safe and removing it.

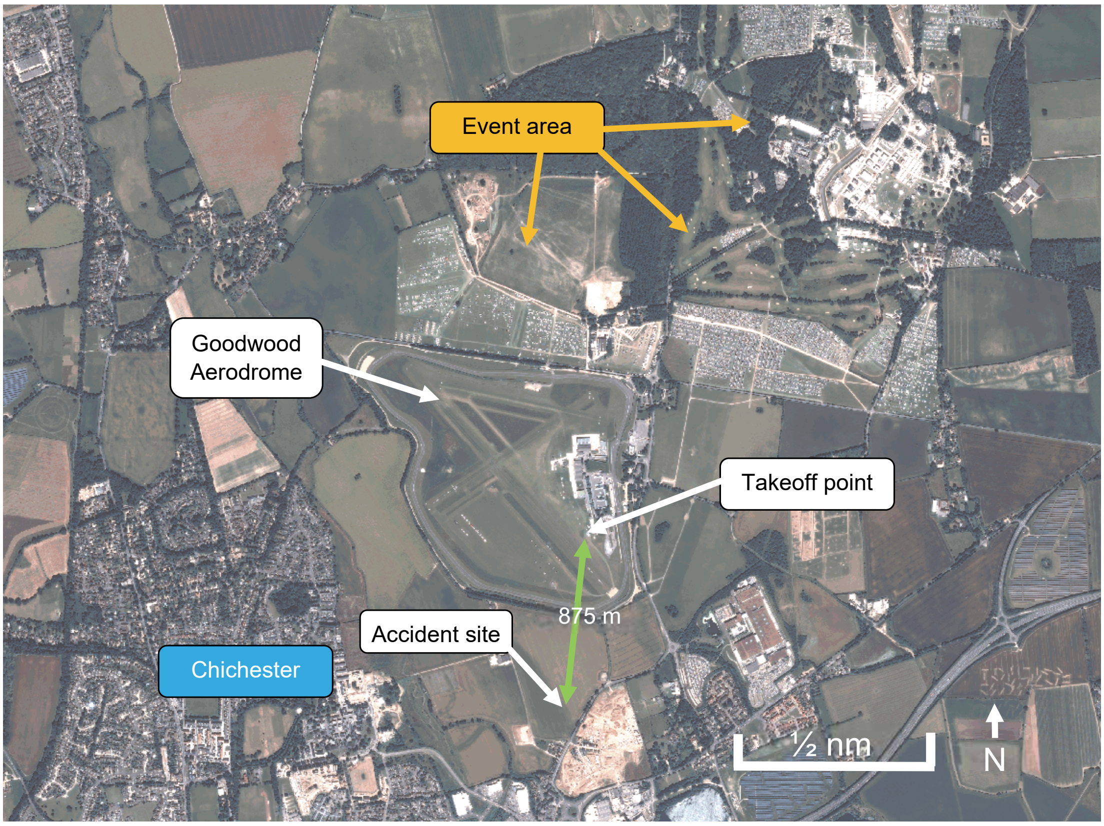

Figure 2

Goodwood Aerodrome and surrounding area on 4 July 2019
© CNES (2019), Distribution Airbus DS

Operator's personnel

The operator's OSCs defined three key personnel in the organisation:

Remote pilot

The remote pilot held a Remote Pilot Licence issued by the Australian CASA. He was also the operator's Chief Remote Pilot and their only pilot that was authorised to operate UAVs up to 150 kg. A licence was not required by the CAA for this operation in the UK.

The OSC stated that the Chief Remote Pilot was responsible for all operational matters affecting the safety of operations. As such his roles and responsibilities included:

- *'ensure that operations are conducted in compliance with the CAA*
- *monitor and maintain operational standards and supervise RP(s) who work under the authority of operator*
- *develop applications for approvals and permissions where required to facilitate operations*
- *develop checklists and procedures relating to flight operations.'*

Maintenance Controller

The OSC stated that the maintenance controller was responsible for ensuring the maintenance of the UAS in accordance with the manufacturer's specifications. His roles and responsibilities included:

- *'control of all UAS maintenance*
- *maintain a record of UAS defects and any unserviceability*
- *ensure that specialist equipment items including payload equipment are serviceable*
- *investigate all significant defects in the UAS.'*

CEO

The CEO was ultimately responsible for ensuring that any operations were conducted in adherence to the operator's '*strict safety standards*' and under the control and authority of the Chief Remote Pilot and Maintenance Controller.

Weather

An aftercast provided by the Met Office stated that at the time of the accident the aerodrome and surrounding area was under a ridge of high pressure. The weather was generally fine with largely clear skies. The winds through the lower part of the atmosphere were relatively light and variable in direction, varying between 030° and 130° but less than 8 kt. Once the UA had reached an altitude of around 6,000 ft and above, the wind direction became more north-westerly at 8 to 15 kt. The atmospheric pressure was 1024 hPa.

Aerodrome information

Goodwood Aerodrome is situated 1.5 nm north-north-east of Chichester, West Sussex. The city has a population of approximately 27,000[4] people. Between 4 and 7 July 2019, a large public event was taking place about 1 nm to the north-east of the aerodrome at Goodwood House. On the day of the accident there were reported to be 35,000 attendees at the event.

The aerodrome has four grass runways, orientated 14/32 and 06/24. Due to the nearby public event, special areas were designated on the aerodrome for the arrival and departure of helicopters used to transport visitors. Additional parking and static display areas were also provided.

The Aerodrome Flight Information Service operated on a frequency of 122.455 MHz. Located on the southern edge of the aerodrome is a VOR/DME navigation aid operating on a paired frequency of 114.75 MHz. The DME transmits on 1055 MHz and receives on 1118 MHz.

The aerodrome is situated in Class G airspace[5] and has an ATZ extending to 2 nm laterally and 2,109 ft amsl vertically. Aircraft movements are assisted by an Aerodrome Flight Information Service. There is Class A airspace[6] with a base of FL65[7] above Goodwood Aerodrome which includes a holding pattern between FL130 and FL70, aligned on the Goodwood VOR, for arrivals to London Gatwick Airport (Figure 3).

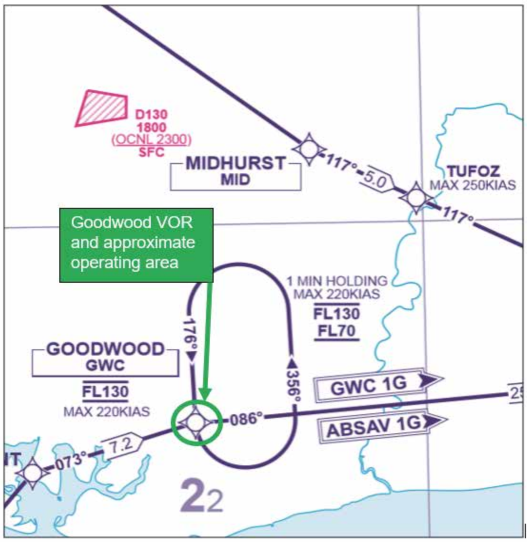

Figure 3

Holding pattern aligned on Goodwood VOR

Footnote

4 Source, UK 2011 census.

5 In Class G airspace, aircraft may fly when and where they like, subject to a set of simple rules. Although there is no legal requirement to do so, many pilots notify ATC of their presence and intentions and pilots take full responsibility for their own safety, although they can ask for help. [NATS website - https://www.nats.aero/ae-home/introduction-to-airspace/ accessed January 2021]

6 In Class A airspace, only IFR flying is permitted. It is the most strictly regulated airspace where pilots must comply with ATC instructions at all times. Aircraft are separated from all other traffic and the users of this airspace are mainly airlines and business jets. [NATS website - see footnote above]

7 A FL (flight level) is the height amsl in hundreds of feet when ISA conditions exist.

Accident site

The UA came to rest inverted in a field of wheat, 875 m south-south-west of the takeoff point. The crop was dry and there was no post-impact fire. The accident site was 40 m from the nearest building which was in a group of houses on the north-eastern edge of Chichester, (Figure 4).

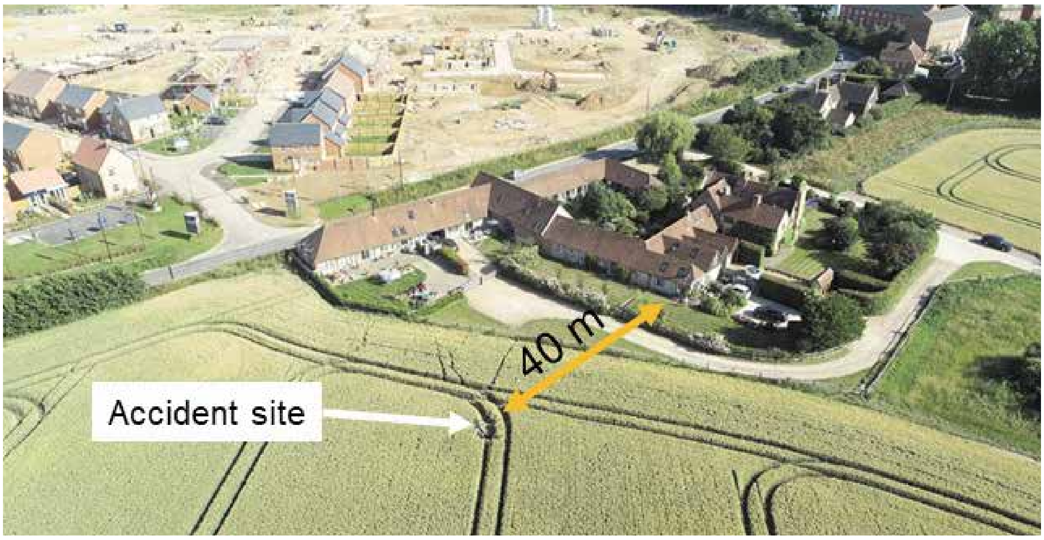

Figure 4
Accident site, looking south

By the time the AAIB arrived, the operator had removed the main battery and placed it away from the crop (Figure 5).

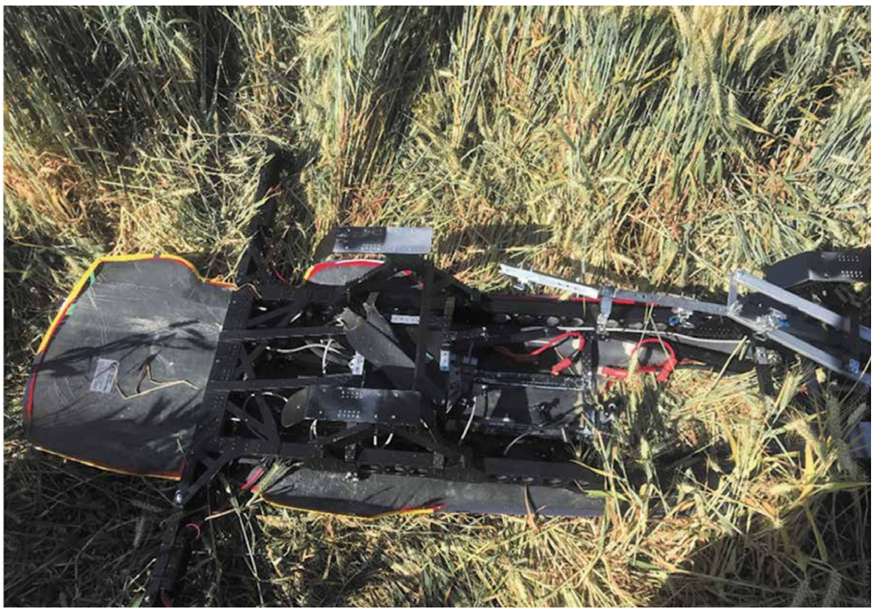

Figure 5
UA as found (inverted) at the accident site

Aerodrome response

Goodwood Aerodrome was aware of the planned flights and the aerodrome and ATZ were temporarily closed to aircraft by NOTAM[8] between 1115 and 1145 hrs, to allow the UAS demonstration flight to take place in this airspace.

The aerodrome's RFFS was equipped with, and trained to use, breathing apparatus. In the event of a fire involving the UA's batteries, they would have been able to engage in appropriate firefighting activities.

Description of the Airspeeder

The Alauda Airspeeder Mk II is an unmanned, radio-controlled, battery-powered quadcopter measuring 3 m long and 1.5 m wide with a maximum takeoff weight of 95 kg. The UA was constructed from an aluminium frame, to which the motors, controllers and battery were attached, along with a fibreglass outer shell (Figure 6). The operator had built two UA specifically for use at this event. These were ¾ size versions of what was planned to be a full-size, human-carrying racing aircraft (Mk IV), which was expected to have a takeoff mass of around 250 kg. The UA was controlled by a ground-based, hand-held transmitter and was reported to be capable of speeds of up to 80 km/h (43 kt).

Figure 6
Alauda Airspeeder Mk II (exemplar model)

Each of the four 32-inch propellers were powered by a brushless DC motor. Each motor had a dedicated Electronic Speed Controller (ESC) which supplied high voltage from the battery to the motors, based on the commands from the flight control system. This lithium polymer battery was of a bespoke design, operating in the 42 to 58 V range for up to 8 minutes.

Footnote

8 NOTAM reference L4473/19.

Flight control system

The flight control system was powered by a dedicated 7.2 V battery. Throttle and flight control commands were received by the on-board controller from a 915 MHz radio receiver. These commands were processed, along with inputs from two Inertial Measurement Units (IMUs), to produce the motor commands. The IMUs were used as a basic stability and control system; if no input was supplied by the pilot, the UA should self-level.

The remote pilot's transmitter contained a graphical signal strength meter display which was based on the strength of the signal received by the aircraft. In the event of loss of connectivity, the transmitter's 'telemetry loss alarm' provides an audible warning. The onboard control system will also freeze the current throttle command to each of the motors but will self-level the UA using the IMU sensors. The effect of this was that the UA would continue flying the last known command but at a level attitude.

Kill switch

The flight controller power supply was routed through a relay, which was controlled by a kill switch. This relay was wired in the 'Normally Closed (NC)' position meaning that if the kill switch was unpowered, power was still available to the flight controller (Figure 7). When activated, the kill switch opened the relay, cutting the power to the flight controller. With the control system unpowered, the ESCs would receive no command and the motors would stop.

The kill switch was powered by an independent 7.2 V battery and operated on a different frequency (433 MHz LoRa[9]) and control system to the normal flight control system. This system was also used to allow the UA to be safely electrically isolated during manual handling on the ground.

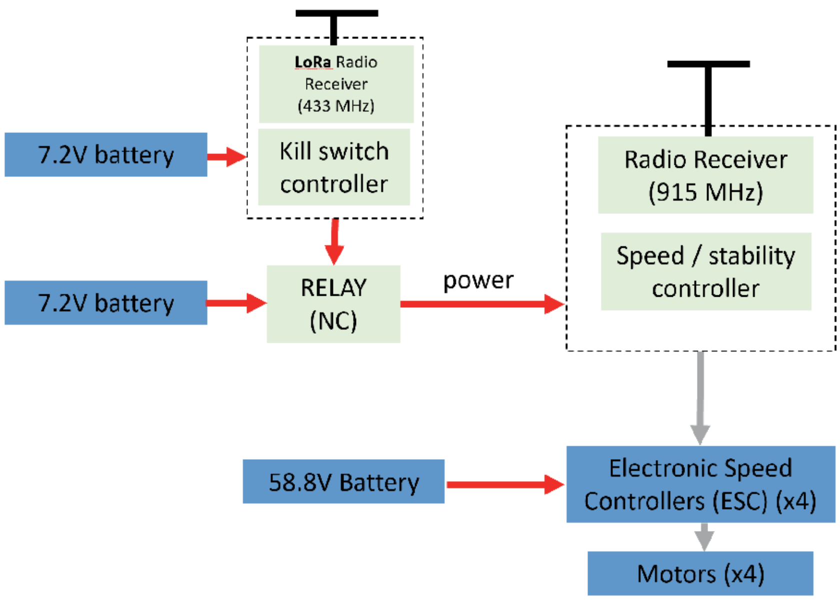

Figure 7

On-board control system schematic

Footnote

[9] LoRa (Long Range) is a low cost, long range (up to 10 km), low power wireless transmission protocol.

The ground-based part of the kill switch was a transmitter connected to a laptop via a trailing USB cable. All of the transmitter's electronics were exposed with no protective enclosure and, when used, the antenna and electronics hung underneath the laptop on the USB cable (Figure 8).

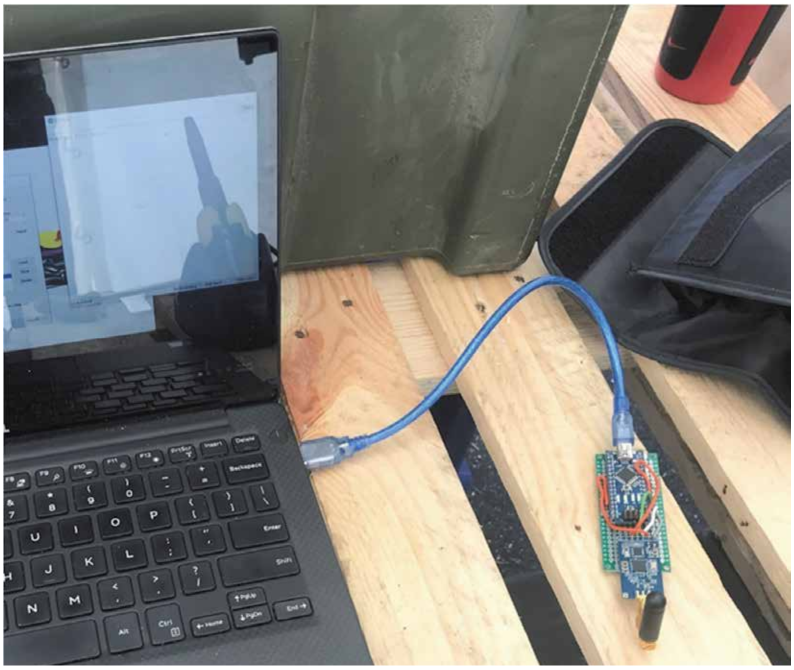

Figure 8
Ground-based kill switch

To activate the kill switch, a spotter was required to enter a command into a terminal on the laptop which communicated this to the USB transmitter. There was no two-way communication in the kill switch system. This meant that if connectivity was lost, it would remain unknown until an attempt was made to use the system.

On the UA both the kill switch and flight controller were packaged into an IP55[10] box with holes removed in the sides to allow cable access. This box was interchangeable between aircraft.

Other systems

The CAA exemption required the operator to operate in accordance with OSC Volume 1, which included fitting an altitude and battery voltage monitoring telemetry system.

There was no Global Navigation Satellite System (GNSS) position system fitted and no return-to-home function available, nor was there required to be. If control was lost, the only back up was the kill switch. If the kill switch failed to operate, the UA would continue to fly until the main battery depleted.

Footnote

[10] An IP55 enclosure is one which can protect from dust ingress and Low-Pressure water jets from any direction.

Detailed examination of the wreckage

Airframe

The airframe had suffered permanent distortion and cracking from the impact, but no preaccident anomalies were found.

Main battery

The main battery had sustained some impact damage but remained intact within its case. Although initially the battery appeared stable, it was later dismantled by the operator into individual cells when it became warm. The individual cells were then disposed of by the operator before the AAIB was able to inspect them.

Flight control system transmitter

Examination of the transmitter revealed that the battery charge was full. The transmitter settings were examined in detail and are covered in the '*Radio control'* section.

Flight control box

The lid of the flight control box, containing the UA control systems, had detached in the accident but the electronic control boards were all present. Only one of the 7.2 V batteries was present, the other was not recovered.

Flight control system receiver

The flight control circuit board was present, but the operator had disconnected the ESC connection wires prior to AAIB arrival. The radio receiver, which was normally slotted into the circuit board, had detached and broken into several pieces (Figure 9). This damage was likely caused in the impact. Failure or loss of this component would lead to loss of link between the UA and pilot.

All of the other components appeared to be present.

Kill switch

Initial examination of the on-board kill switch circuit board showed that the relay and one of the battery power supply leads had detached from the board. Loss of either of these components would render the kill switch inoperative. The antenna and the rest of the components all appeared to be in place.

The system was powered and tested in the presence of the operator. The relay and power supply lead were re-attached to the circuit board and the kill switch tested on a number of occasions, each time successfully.

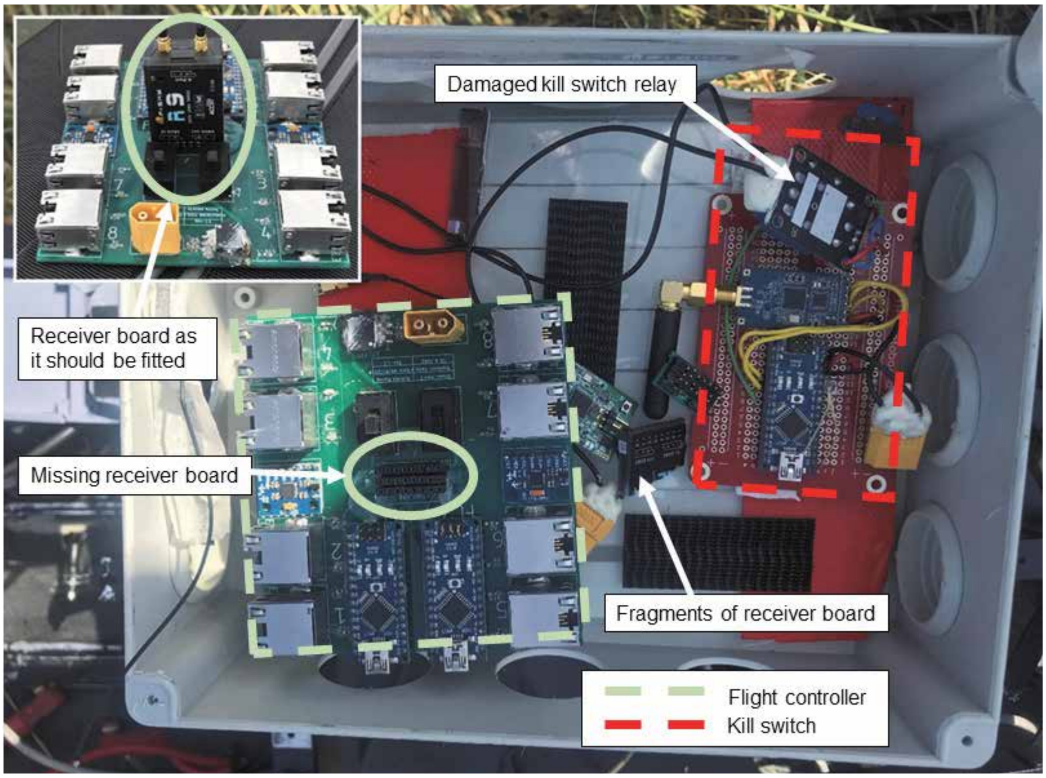

Figure 9
Flight controls box at accident site

Examination of circuit boards

Initial examination of the circuit boards revealed some concerns regarding build quality and workmanship. The boards were populated with 'hobbyist' components with exposed wiring, large amounts of solder and lumps of adhesive. The kill switch used an electronics prototyping board with a number of jumper wires instead of a printed circuit. Failure of any of these wires would render the kill switch inoperative (Figure 10).

Each circuit board was X-rayed. This revealed no dry solder joints but had large quantities of solder present.

The AAIB engaged a specialist company who provided an experienced IPC[11] mastertrainer/instructor to examine the circuit boards against the IPC A-610 standard. This standard provides acceptance requirements for the manufacture of electrical and electronic assemblies. It defines three classes, which depends on the application of the electronic assembly. Class 1 is aimed at non-critical items, up to Class 3 which is for high performance products where equipment downtime cannot be tolerated. For this application, Class 3 seemed to be appropriate.

Footnote

[11] Institute of Printed Circuits.

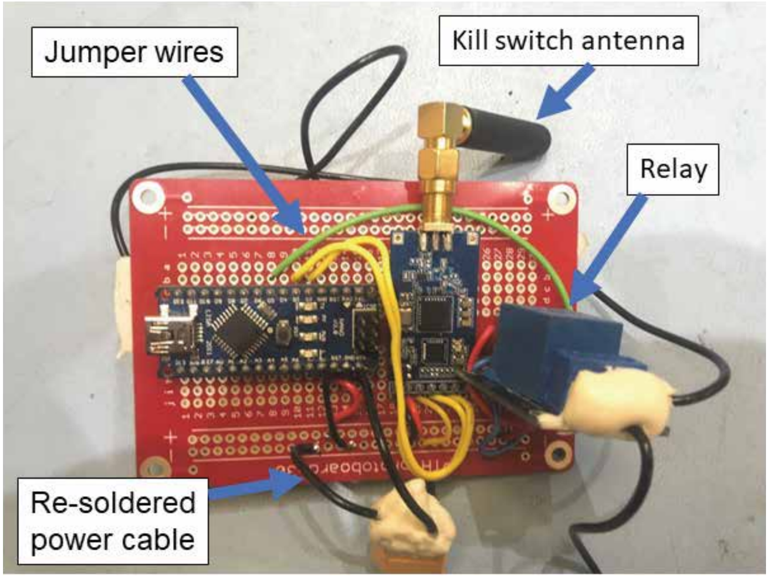

Figure 10
Kill switch on-board circuit board

The examination revealed a number of issues with the flight control system and both the airborne and ground-based kill switch assemblies. All the assemblies failed an evaluation against all IPC A-610 classes due to quality and workmanship issues. Examples included misaligned components, burnt insulation, the use of solder bridges, excessive flux residues and a power connector that appeared to be installed in the incorrect orientation when compared to the drawn orientation on the circuit board (Figure 11).

Figure 11
Power connector installation, solder bridge and evidence of burnt insulation

CAA UAS Unit

The CAA's UAS Unit consists of two sections, the Policy Team and the Sector Team. The Sector Team has responsibility for the oversight and management of OSC's. At the time of the application, the CAA's UAS Sector Team comprised of a Section Lead, one UAS Technical Inspector and two UAS Technical Surveyors. There were plans to recruit a further two Inspectors and two Surveyors. The Section Lead, who was the signatory on the exemption, had joined the CAA in May 2018 from an emergency services organisation where they had introduced UAS operations; he has since left the CAA. Other members of the UAS Sector Team joined the CAA from university and initially worked in data entry roles within the CAA's Shared Services Centre. The Technical Inspector took up the role in January 2019 after working as a UAS Technical Surveyor for approximately one year. One UAS Technical Surveyor, was still undergoing initial training and development.

CAA exemption application process

At the time of the accident flight, in order to fly this weight of UAS in the UK, an exemption from certain parts of the UK Air Navigation Order (ANO) 2016 was required from the CAA. Under new UAS regulations, introduced on 31 December 2020 this weight of UAS would require an Operational Authorisation[12]. Details of the process to be followed and the requirements to be met to gain the exemption, along with guidance material, were contained in Civil Aviation Publication (CAP) 722[13].

For this weight of UAS an Operating Safety Case (OSC) was required.

The OSC document consists of three sections:

OSC Volume 1 – Operations Manual

OSC Volume 2 – Systems

OSC Volume 3 – Safety Assessment

Templates are provided for each section, with section headings detailing the minimum subject areas that need to be addressed.

The application process was initiated by the operator who completed form SRG1320 and submitted it with the relevant supporting information, including the OSC, and an application fee to the CAA. Following an initial administration review of the application, to ensure it is complete, it is then sent to the CAA's UAS Sector Team for technical consideration.

CAP 722, Edition 6, detailed that the CAA takes a proportional approach to each application with differing levels of assurance and assessment required, depending on the intended operation. They categorised each application as A, B or C, depending on its technical complexity, operating environment complexity and mass (Figure 12)[14]. The application for the flights at Goodwood using the Airspeeder Mk II was categorised as B.

Footnote

[12] CAP2013: Air Navigation Order 2020 Amendment – Guidance for unmanned aircraft system users (caa.co.uk) https://publicapps.caa.co.uk/docs/33/Air%20Navigation%20Order%202020%20Amendment%20Guidance%20for%20unmanned%20aircraft%20system%20users%20(CAP2013).pdf [accessed 24/12/2020].

[13] At the time of the accident, CAP 722 Edition 6 was extant. Edition 7 was issued on 23 July 2019 and issue 8 on 5 November 2020. All references to CAP 722 in this report are to Edition 6, unless otherwise stated.

[14] CAP 722 Edition 7 reclassified these categories to low, medium and high risk/complexity with less emphasis on aircraft mass. However, Edition 6 was extant at the time of the accident.

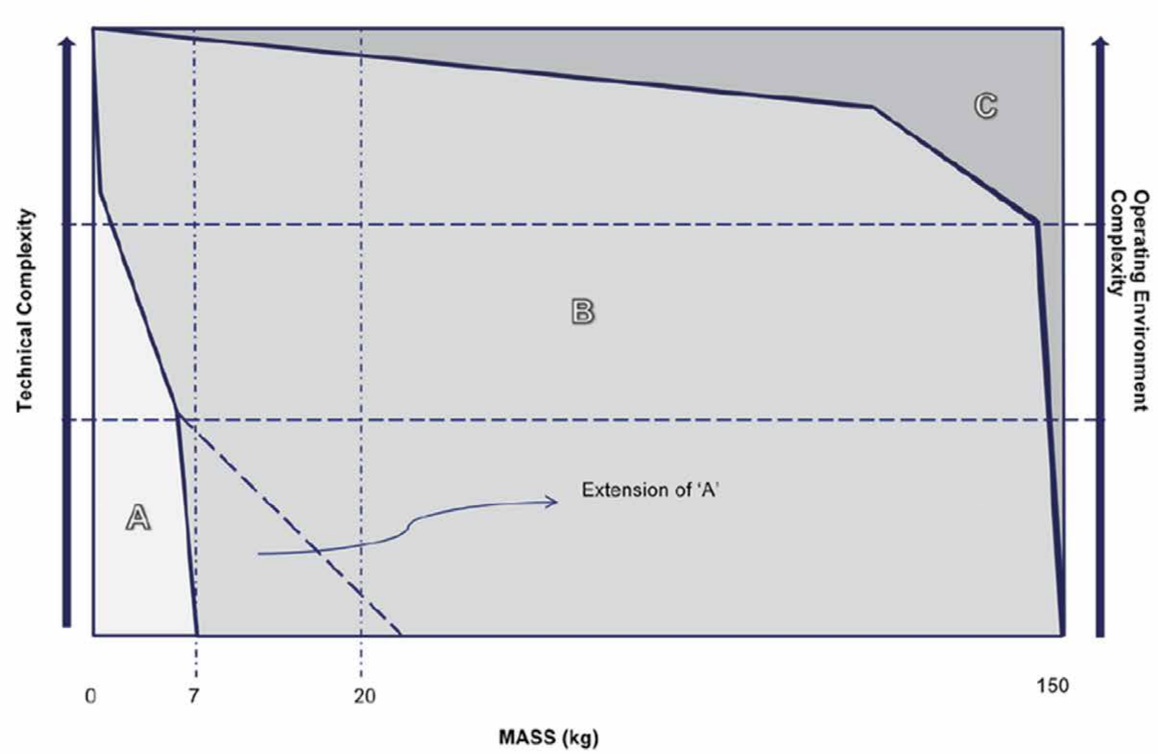

Figure 12

CAP 722 UAS Approvals Requirements Map

Once satisfied that the proposed operation met the safety requirements, an exemption may be issued, which could include any specific conditions that are required to be met. This process typically took 'several weeks' but depended on the type and complexity of the operation. The CAA did not publish a 'standard duration' for granting an exemption.

An exemption can only be signed by an authorised person. This authority was granted based on an individual's experience and capability.

The exemption allowed a UAS to be operated outside the limitations of the ANO but within specific conditions defined in the exemption. Any breach of these conditions was equivalent to a breach of the ANO.

The CAA stated that the level of resources available meant it was not possible for the UAS Sector Team to follow up every exemption. It was also stated that, in accordance with the wider CAA approach to Performance Based Oversight, the level of oversight was primarily guided by the level of the assessed safety risk and the UAS's complexity. It was also stated that, for operations that it considers to be 'complex', the CAA often visit to observe an organisation and how it is complying with the exemption. It was confirmed that the CAA have a process for auditing exemption holders, but its use is dependent on the complexity and assessed safety risk of the operation.

Airspeeder exemption application process

The initial application was made by the operator on 9 May 2019 with a view to receiving approval in time for the first planned flight on 1 July 2019. The application included an OSC along with other relevant supporting documentation. The application for an exemption was necessary as the UA's takeoff weight was in excess of 20 kg but less than 150 kg[15].

After clarification of some points, the CAA's administrative review was completed on 3 June 2019 and the application passed on to its UAS Sector Team for technical review.

The application was passed to a UAS Technical Surveyor, but as it related to a UA over 20 kg, it was passed on to a UAS Inspector for review. The Technical Surveyor remained involved in the process for education and experience purposes.

The UAS Sector Team made a preliminary review of the submission which resulted in several questions being sent to the operator for clarification on 20 June 2019. A more formal review of the OSC, using the CAA's OSC checklist, was made on 21 June 2019. This highlighted further areas in the application that needed further explanation and/or amendment of the OSC.

The operator provided a revised version of Volume 1 of the OSC on 24 June 2019 and a revised version of Volume 2 on 25 June 2019.

A meeting then took place between a CAA UAS Airworthiness Policy Specialist, the UAS Technical Inspector and the Technical Surveyor. This was an informal peer review and reportedly covered the points in the OSC that the Technical Surveyor felt he was unsure of. Discussions included operational heights and speeds and the resultant trajectories and energy, and technical aspects including a lack of redundancy and the reliance on a kill switch which, if operated, would result in a crash. Overall, they felt that Volume 3, '*Safety Risk Assessment'*, was not sufficiently detailed. It was agreed that an exemption would not be issued until all the identified issues had been resolved. There was no formal record of the agreed actions. A detailed email explaining the areas requiring attention and suggested adjustments to the operating conditions was sent to the operator on 26 June 2019. Part of this email contained a 'Report Overview' which stated:

> *'Technical assessment of the OSC submitted revealed that the proposed flight operation is intermediate in terms of complexity, however, it poses high safety risk for the general members of the public. The OSC proposed two different areas of operation, namely map A and B, both within Goodwood Aerodrome vicinity.*
>
> *Aircraft system assessment indicated that the platform is still in the development phase as it lacked some of the standard automated safety features such as Return to home function, automate obstacle avoidance functionality or Geofencing*

Footnote

15 Civil Aviation Authority Unmanned Aircraft System Operations in UK Airspace – Guidance CAP 722 Edition 6.

capability, etc. More importantly, critical technical recovery/ redundancy systems appear to be missing or not integrated to the platform as part of the design, as per the Volume 2 Operations manual.

Assessment of Map A [Figure 13] *indicated that the area of operation and the designated flight perimeter is conceivable with some minor adjustments to the operating conditions, as follows:*

> *Exclusion zone/ minimum separation distance from person, vessels, vehicle or structure must be greater than 30 metres.*
>
> - *Height of the aircraft must be significantly reduced to more reasonable height above the surface.*
> - *Flights within map A to be conducted with full co-ordination with the Aerodrome operator.*
> - *Operation to be conducted with suitable number of spotters/ observers and marshals deployed in the field during flight.'*

Whilst the CAA's internal review was progressing the UAS Technical Surveyor contacted CASA as the aircraft had been built by an Australian company and it had previously operated under CASA permissions. References to these CASA permissions were included in the operators OSC submitted to the CAA. In response CASA requested that the CAA seek the operator's permission before they could release any information relating to the operator. The CAA stated at this point they decided to base their assessment, and the resulting mitigations, solely on the information that had been provided by the operator.

Further exchanges took place with the operator to clarify some outstanding points. One of these was a request to modify the takeoff area to an area located further away from the spectator's location; this was moved to the threshold of Runway 32. The operator submitted a final version of the OSC on 3 July 2019. The UAS Sector Team did not pass the revised documents to the Policy Specialist or the UAS Policy Team for review prior to the exemption being issued.

The CAA did not meet with the operator or inspect the aircraft. The UAS surveyor presented the proposed exemption and associated documentation to the Sector Lead of the UAS section who approved it on 3 July 2019. The CAA issued an exemption the same day (Appendix A).

During an interview with the AAIB, the CAA indicated that this application did require a rapid turnaround but stated that there were no time pressures. They also indicated that they would not have granted the exemption in time for the public display unless they were comfortable with the details of the application.

On 3 July, the UAS Inspector requested a private demonstration flight the following day but this was not a condition of the exemption. At about 0900 hrs on 4 July, the day of the accident, the CAA spoke with the operator who informed them that a private demonstration would not be possible in the 30-minute time slot already allocated to the scheduled public demonstration flight. The CAA were not aware of the unsuccessful flight undertaken by the operator on the 3 July until after they arrived at Goodwood on 4 July as the operator had not reported it.

On 4 July, the UAS Inspector and UAS Surveyor arrived at Goodwood approximately 50 minutes before the accident flight. They asked to observe the pre-flight briefing, but this was declined as there was little time before the scheduled demonstration flight and the operating crew had already commenced their pre-flight checks. The window for the flight was limited as the airspace had been closed from 1115 to 1145 hrs. The CAA staff accepted this situation as no prior arrangements to inspect the UAS had been made and the exemption had already been issued. They were directed to the hospitality area to observe the flight with the invited audience which included several journalists.

After the accident, and before they left the aerodrome, the CAA staff informed the operator that the exemption would be withdrawn, and that a written notification would follow.

CAA exemption

The exemption was signed on 3 July 2019, and was valid between 3 to 7 July 2019, for demonstration flights in two pre-defined areas at the event (Appendix A). For the display at Goodwood Aerodrome, it included several conditions, including speed and altitude limitations, insurance requirements, occurrence reporting and geographic limitations. The flight also had to be conducted in accordance with the operator’s OSC.

Part 3 of the exemption indicated the aircraft was not to be flown unless a list of subsequent conditions ((a) to (l)) were adhered to. Condition (i) contained the geographical limitations:

> *‘3. This Exemption is granted subject to the following conditions, namely, that the unmanned aircraft shall not be flown:*
>
> …
>
> *(i) Within a distance of 30 metres of any person, vessel, vehicle or structure that is not under the control of the operator or the chief remote pilot, provided that the conditions below are met;*
>
> *i. The operation may only be carried out in accordance with the operating procedures set out in the said operations manual;*
>
> *ii. The horizontal distance between the chief remote pilot and the small unmanned aircraft must not exceed 150 metres.*
>
> *iii. The speed of the unmanned aircraft must not exceed 5 metres per second or a slow walking pace when operating in Map B.*
>
> *iv. The speed of the unmanned aircraft must not exceed 11 metres per second when operating in Map A.’*

The CAA were contacted to discuss these conditions as it was not initially clear whether parts i to iv were conditional on the UA being operated within 30 m of a person, vessel or structure. They confirmed that the text in this exemption was adapted from previous exemptions they had issued. Their intent was that the UA should not be operated within 30 m of a person, vessel or structure and that conditions i to iv were not a sub-condition but should have been considered separately.

Operating Safety Case documentation

The AAIB were provided a copy of the OSC. This was reviewed, and a number of inconsistencies, misrepresentations and omissions were identified. These are discussed throughout this report. Discrepancies included the declaration of maximum takeoff weight (67 kg in one section, 95 kg in others) and a maximum display speed during the display (60 km/h (16.7 m/s) verses 11 m/s as limited by the exemption).

Operational area

From the available documentation, the CAA recognised that the UAS was relatively unsophisticated in its design, had limited redundancy and multiple single points of failure. It did not have any equipment to monitor its position, and therefore could not be 'geo-fenced[16]' or contain any safety systems[17] which could be activated in the event of loss of control. The exemption therefore limited its operation to the area defined in the OSC. Additional limitations on its operating speed and altitude were also made to ensure that in the event of any anomalies in its operation, the kill switch could be operated, and it would crash and remain at least 30 m from the viewing platform. These limitations were included in a 'Flight Approval Form' which formed part of OSC Volume 1 (Figure 13).

All persons were to be kept clear of the flight areas. A spotter, in contact with the remote pilot, was to be positioned 150 m from the remote pilot to ensure the UA did not stray outside of the defined area.

Invited guests were to be located on the viewing platform. The area in orange in Figure 13 is the flight area where the operator was to perform the display. The area shaded red is the safety buffer zone which the OSC stated that if flown in '*will require a response from spotter to alert the RP* [Remote Pilot] *of the perimeter breach and initiate redirection procedures'.*

The operating limitations were discussed between the CAA and operator during the application process. The proposal was that the UA would be operated no closer than 30 m to the invited guests, a distance based on the Australian '*Drone Safety Rules*'[18] and but less stringent than the UK regulations (50 m)[19]. The CAA requested the 30 m distance be

Footnote

[16] Geo-fencing is a virtual perimeter that can be defined by geographical coordinates. Using onboard GNSS position data, such as GPS, the UAS's operation can be programmed to remain within the selected area.

[17] Safety systems include automated return to takeoff point (return to home), controlled descents, hover land, parachutes etc.

[18] CASA Drone Safety Rules website https://www.casa.gov.au/drones/rules/drone-safety-rules (accessed 12/10/20)

[19] UK Air Navigation Order 2016 The Air Navigation Order 2016 (legislation.gov.uk) (accessed 23/12/20)

increased to allow additional time and space to react should there be an emergency. This resulted in the sizing and location of the safety buffer zone.

Figure 13

Operating area detail from Flight Approval Form in OSC Volume 1

Initially, the operator requested to fly up to 400 ft but this was reduced to an approximation of the tree height of 67 ft (20 m). The speed limit of 11 m/s was proposed by the operator and based on some simple trajectory calculations they had performed. The CAA indicated that due to the simplicity (absence of aerodynamics, control response, environmental effects etc), they could not be included as a justification in the OSCs.

Review of operating area

The display area and safety buffer zone defined in the OSC were generated using the eastern edge of Runway 32 as the edge of the display area. This display area was drawn using a Google Earth image from 2015. In August 2017, the aerodrome modified Runway 14/32 by reducing its width from 45 m to 30 m by reducing the eastern edge by 15 m. This meant the display area defined in the OSC did not represent the correct runway geometry on the day of the accident. If the pilot was using the edge of Runway 14/32 as the edge of display area, the width would be 15 m less than that defined in the OSC. The AIP entry at the time of the application contained up to date information.

The display area dimensions (orange area in Figure 14) defined in the OSC were approximately 90 m x 450 m, with the safety buffer zone extending towards the viewing platform by 45 m. The viewing platform was 30 m from the edge of the red safety buffer zone (Figure 13).

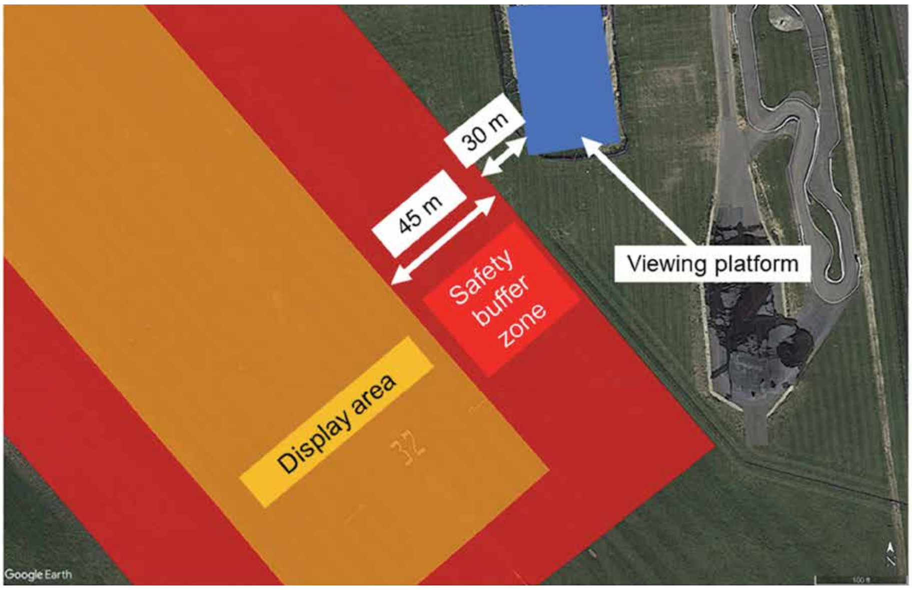

Figure 14

Viewing platform distances from display area and safety buffer zone

Trajectory analysis

The OSC did not define any trajectory or kinetic energy impact analysis in the event of UA failure within the display or safety buffer zones. The CAA corroborated the calculations performed by the operator which were based on a takeoff mass of 95 kg, maximum altitude of 67 ft (20 m) and speed limit of 11 m/s. Assuming the effects of gravity and forward speed only, in the event power loss or the kill switch being activated at the speed limit and maximum altitude, the UA would impact the ground within 2.02 seconds and cover a ground distance of 22 m (ie within 30 m).

This assessment did not assume any reaction time of the remote pilot or the spotter who was controlling the kill switch. For every additional second increase in reaction time, the UA could travel up to an additional 11 m. If the kill switch was required to be initiated, with the UA at a height of 20 m and 11 m/s, the spotter would have to activate it within 2.1 seconds to ensure the UA struck the ground within a horizontal distance of 45 m (width of safety buffer zone) or less. Similarly, to contain the UA within 75 m (safety buffer plus distance to viewing platform), it would need to be operated within 4.8 seconds.

The OSC indicated that the maximum operating speed for this display was to be 60 km/h (16.7 m/s). At this speed, these times would be reduced to 0.7 and 2.5 seconds respectively.

CAP 722 did not define any nominal reaction times. Although not applicable at the time of the accident, the EASA Guidance Material and Acceptable Means of Compliance for UAS operations[20] considers a reaction time of 2 seconds.

Footnote

[20] European Union Aviation Safety Agency Acceptable Means of Compliance (AMC) and Guidance Material (GM) to Part-UAS UAS operations in the 'open' and 'specific' categories, Issue 1, 9 October 2019.

Action in the event of signal loss

OSC Volume 1 contained a section on 'UAV signal loss' which stated:

> *'Should signal be lost the pilot will repeat "DARK" repeatedly over radio. The spotters should immediately observe whether or not there is anything that can be damaged, most importantly that there are no people in the vicinity and that the UAV is not moving towards people or property. If people are present, they will be immediately ushered away. The pilot in command will try to regain connection by moving closer or around obstacles. If connection is not made the pilot will repeat "kill" over the radio at which point if the UAV is over clear ground the kill switch will be activated, and the UAV will then crash land.'*

Kinetic energy

CAP 722 required assessments of kinetic energy limits only for flights over people. These assessments considered a free-fall case and one for the UA operating at its maximum forward speed.

As the planned flights were to be geographically constrained, no kinetic energy calculations were included in the OSC. The CAA did perform some calculations based on the UA free-falling from 20 m. Neglecting air resistance, the impact velocity would be 19.8 m/s and, with an UA mass of 95 kg, kinetic energy at impact would be 18,700 joules. The OSC indicated that the UA was capable of speeds of up to 80 km/h (22 m/s) which would result in a Kinetic energy of 22,990 joules at impact.

Information from CASA

In their OSC, the operator made several references to their Australian operations and the permissions granted to them by CASA. There were references to both operational aspects and design and manufacture. They stated that the UA was required to be submitted to CASA for testing, inspection and assessments, and that:

> *'certification requirements were compulsory in areas such as:*
>
> > *Structures/fatigue*
> > *Frangibility*
> > *Mechanical systems*
> > *Propulsion systems*
> > *Avionics*
> > *Remote pilot station*
> > *Data link*
> > *Flight test'*

CASA was asked by the AAIB to provide details of the scope and outcome of these activities and to provide any submissions made by the operator to show compliance with the requirements. CASA advised the AAIB that:

> *'The aircraft was not subject to any specific assessment by CASA.'*

and:

> *'There were no RPA[21] certification requirements identified to the applicant. In Australia, the RPA is considered a medium category RPA which does not have to be certified. A discussion with* [the operator] *identified that their aim was to place a person in the RPA, and it was stated that* [the operator] *should contact the airworthiness and engineering branch in relation to this operation.* [The operator] *were informed that if the MTOW of the RPA exceeds 150kgs, an airworthiness certificate would be required. It was also stated that placing a person in the RPA would make it a manned aircraft.'*

The operator indicated that CASA had witnessed a flight and were given free access to examine the aircraft.

UAS regulation changes

On 11 June 2019 regulations relating to the harmonised use of UAS within Europe were published by EASA. This contained the following regulations (the CAA has also issued CAP1789 that summarises these):

- Commission Implementing Regulation (IR) (EU) 2019/947 on the procedures and rules for the operation of a UA.
- Commission Delegated Regulation (DR) (EU) 2019/945 on a UA and on third country operators.

The DR became applicable on 1 July 2019 and the IR became applicable on 31 December 2020.

Operations of UAS will then be placed into one of three categories:

- *'Open category (less than 25 kg) – operations that present a low (or no) risk to third parties. Operations are to be conducted in accordance with basic and pre-defined characteristics and are not subject to any further authorisation requirements. The open category is divided into operational 'subcategories' A1, A2 and A3. Within each subcategory are classes of UAS that include C0, C1, C2, C3 and C4.*

Footnote

[21] RPA – Remotely piloted aircraft.

- *Specific category – operations that present a greater risk than that of the open category, or where one or more elements of the operation fall outside the boundaries of the open category. Operations will require an operational authorisation from the national aviation authority (ie the CAA in the UK) based on a safety risk assessment.*
- *Certified category – operations that present an equivalent risk to that of manned aviation and will be subject to the same regulatory regime (ie certification of the aircraft, certification of the operator, licensing of the pilot).*'

These changes were reflected in CAA CAP 722 Edition 8, published in November 2020.

Radio control

The remote pilot operated the UA using a hand-held transmitter[22] capable of three-axis and throttle control, which was also fitted with a 'range extender[23]'. The manufacturer did not publish range information, as range is affected by several factors including antennas, topography and local 'noise'. A number of websites listed the range as up to 10 km but with no corresponding transmitter power. In OSC Volume 1 the operator noted that *'the radio transceivers have a range of 40 km and are very resistant to interference and obstacles meaning weak transmission within the line of sight of a UAV is extremely unlikely'.* In OSC Volume 2, this was listed as up to 2 km and in another section, 'a range of 10 km' but with no associated transmitter power.

All previous flights in Australia had been performed using a frequency of 915 MHz and transmitter power of 1 W. The operator indicated in their OSC that due to UK regulations for this frequency, the transmitter power had to be limited to 25 mW.

The operator also noted that for redundancy, two hand-held transmitters were available for controlling the aircraft; however, during the accident flight, the second transmitter was located in their workshop.

Transmitter frequency

The transmitter could be programmed to operate in a number of modes. These included an 'EU' and 'FCC' mode which used different frequencies (868 MHz and 915 MHz respectively) and gave different power options. When the transmitter was examined, it was set to 'FCC' mode with a power of 10 mW. Power options for this mode were 10, 100, 500 mW or up to 1 W. The 25 mW power option was only available in 'EU' mode.

Note 4 of the CAA exemption stated that the operator was responsible for ensuring the frequencies being used complied with Ofcom[24] requirements. Ofcom were contacted by the AAIB for guidance on the two frequencies available. Their online documentation indicated

Footnote

[22] Fr-Sky Taranis X9D.
[23] Fr-Sky R9M Module.
[24] Ofcom is the UK regulator for communication services.

that neither 868 MHz or 915 MHz required a license to operate and that both were allocated to 'Non-specific Short Range Devices'. IR 2030[25] provides requirements for licensing and use of short-range devices in a range of frequency bands. This document stated that short-range devices using a frequency band of 868 to 869.7 MHz are permitted to be used airborne and should have a maximum transmit power of 25 mW. Equipment in the 915 to 918 MHz range was also limited to the same power but was not permitted to be used in airborne applications. Ofcom also indicated that they had no record of being contacted by the operator prior to the flight of 4 July 2019.

Unauthorised use of radio equipment is illegal in the UK and can lead to fines, a prison sentence, forfeiture of the equipment used in the offence and/or a criminal record.

The flight of 3 July and the accident flight were the first two flights using a power of 10 mW. Range information was not published for operations at this lower power but is expected to be lower than 10 km and within the range required for the flight.

Pre-flight checks

Part of the pre-flight checklist required an *'On site signal strength inspection and mapping of any blind spots'.* The procedure for this was not detailed in the OSC but the operator confirmed that this was successfully completed on 3 July. They indicated that the test involved removing the flight control box from the UA and walking it to the boundaries of the flight area, with the antennas facing away from the transmitter to simulate a worst-possible case. The transmitter remained with the remote pilot who monitored the signal strength display. The operator confirmed that the test was successful with signal strength received by the transmitter never less than '*4 of 5 bars*'[26]. The test was only performed using the flight control system; the kill switch system was not tested. No testing was performed with the flight control box inside the UA to examine any shielding effects that the aluminium structure may have had.

The operator confirmed that prior to takeoff, the kill switch was operating correctly as, for safety reasons, it was used to isolate the aircraft. Operation of the kill switch correctly triggered the telemetry loss alarm on the pilot's transmitter.

The operator also confirmed that there had not been any range issues with the flight control system and they had never previously lost control of the aircraft.

In the 'UAV Signal Loss' section of the OSC, it stated that *'All spotters will be equipped with kill switches and radios, spotters will be positioned such that there are no blind spots on the flight path of the UAV in addition a spotter will be next to the pilot in command'*. On the day of the accident, only one kill switch was available which was located with the spotter standing next to the remote pilot.

Footnote

25 IR 2030 – UK Interface Requirements 2030, License Exempt Short Range Devices, November 2018.
26 Signal strength ranged from 0 to 5 with 5 the highest strength.

Radio frequency interference

The operator of the VOR/DME located on the aerodrome confirmed that it was operating normally on the day of the accident with no reported issues. They confirmed that the DME transmit frequency (1,055 MHz), which was the closest to 915 MHz, operates within a narrow frequency band and that *'any emissions greater than 2 MHz from the transmit frequency are at or approaching the noise floor. The likelihood of an emission at 915 MHz is very small'.* The aerodrome RTF frequency was below that of the aircraft controller and the aerodrome operator commented that interference from this frequency was unlikely due to the narrow frequency band they were using. At the time of the accident, these were the highest known power transmitters in the vicinity.

There were no other aircraft operating from the airfield at the time of the accident but there may have been other RF signals present around the aerodrome. Ofcom confirmed that there could have been other users of 915 MHz on the day, including licensed use from mobile phone network providers and other 'Non-specific short-range devices'. Up until the loss of control, there were no intermittent or losses of signal reported for both flights and in pre-flight testing.

Appendix A of the Sixth Edition of CAP 722 details 'Operational Factors for SUA Flights within Congested Areas' and states:

> *'Radio Frequency (RF) interference. Pilots must take account of the possible reduction in operating range in an urban environment due to the heavy use of communications equipment (mobile telephone, Wi-Fi etc.) and other sources of electromagnetic spectrum/RF interference. Mitigation for the consequences of weak or lost GPS signal due to masking by buildings must be considered along with the general RF saturation level. The use of a spectrum analyser is recommended to assist in assessing the level of local electromagnetic and RF congestion in the 2.4 GHz or 35 MHz frequency range.'*

Given that this operation was to be conducted within the airfield boundary, it was not classed as an 'urban environment' so the recommendation for spectrum analysis was not applicable.

Recorded information

The UA was not fitted with a flight recorder and nor was it required to be. The UA was fitted with two cameras, one on the top facing forwards, the other on the bottom facing rearwards. The installation of these cameras was not detailed in the documentation submitted to the CAA.

As this was a demonstration flight, footage was also obtained from the audience located on the roof terrace. A media company were contracted to film the event by the operator and were located on the ground just behind the remote pilot. Footage was available from takeoff until the UA lost control, after which the audience were instructed to take cover. One camera captured the UA in the descent just prior to impact.

Review of video footage

Video footage was reviewed to compare requirements of the CAA exemption and the operation of the aircraft. The review confirmed that, within the camera's field of view, the UA remained intact for the display with no visible failures of the motors, propellers, ESCs, airframe and battery. The footage also revealed a number of items including aircraft parked in front of the aerodrome building (Figure 15) and two fuel bowsers parked within the safety buffer zone. At times, during low-speed turns, the aircraft was pointed directly towards the aerodrome building.

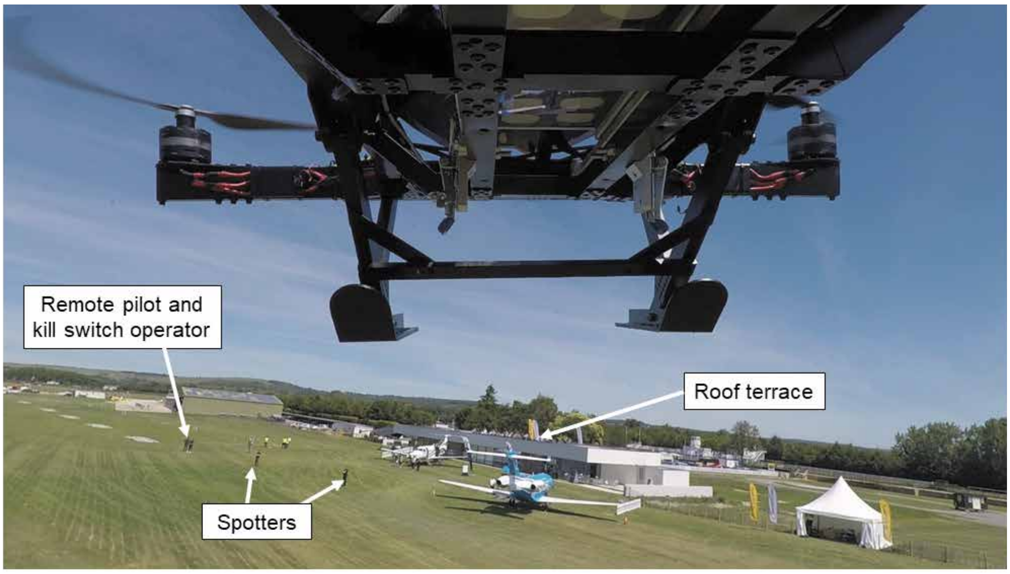

Figure 15

View from bottom rearward-facing camera towards the aerodrome building, just after takeoff

In the '*Operating site planning, assessment, communications, pre-notification and site permissions'* section of the OSC were considerations for operating at the aerodrome. One of these stated:

> *'e) Any aircraft parking lines will be well in excess of minimum safety distances, to the north east and south west of the operating zone'*

Takeoff location

Figure 16 shows the takeoff location detailed in the OSC and the takeoff location ascertained from the video analysis. The aerial imagery is from a satellite image taken on the day of the accident. The aircraft took off 60 m from the aerodrome building and approximately 85 m from the designated takeoff / landing area.

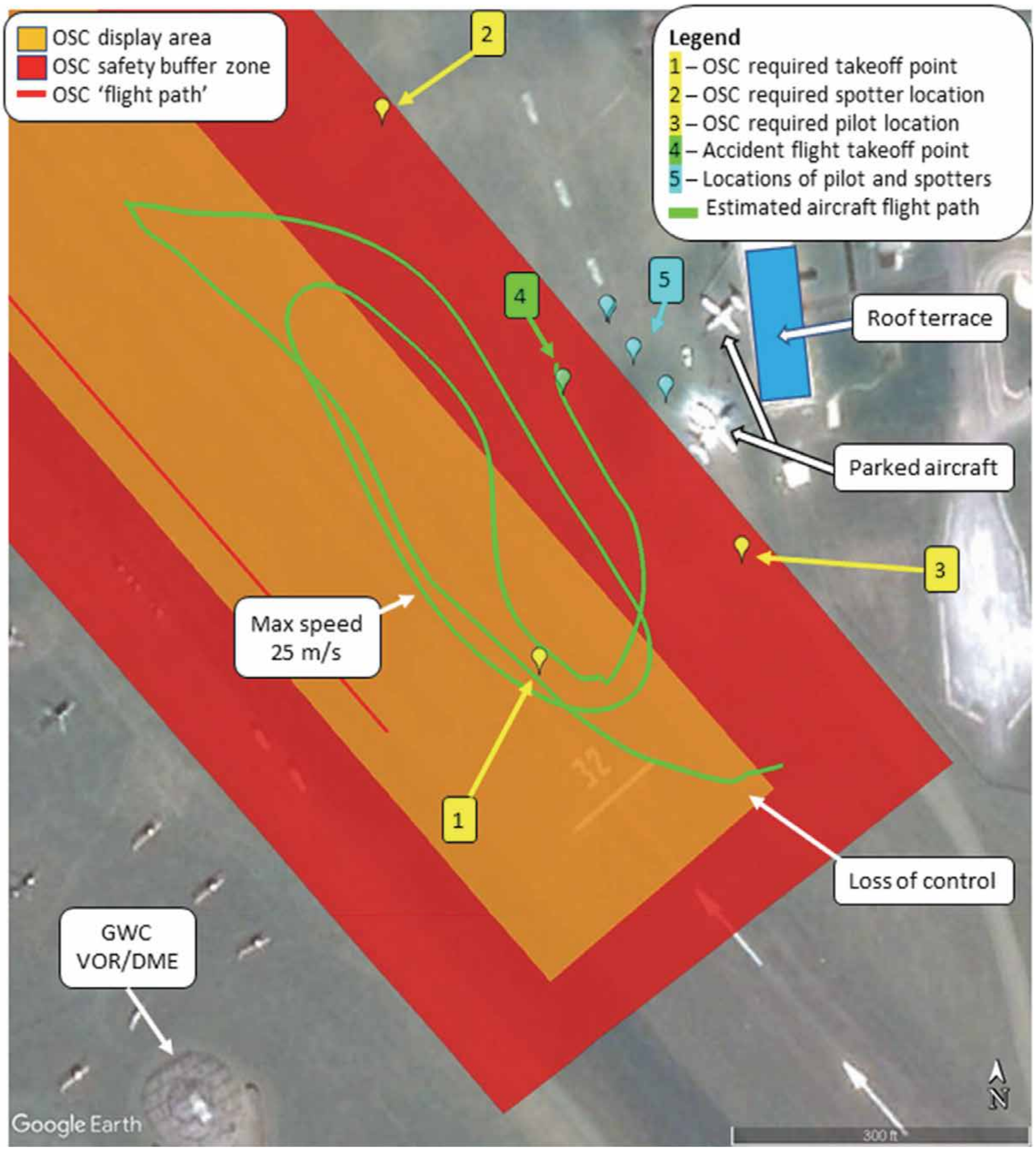

Figure 16

Overhead view of Goodwood Aerodrome showing estimated aircraft flight path, location of personnel and their required locations.
© CNES (2019), Distribution Airbus DS

Remote pilot and spotters

The remote pilot and spotters' locations are shown in Figure 16 and 14. All spotters had their backs to the aerodrome building to watch the display and were in radio contact with each other. There was no spotter located at the 150 m point from the remote pilot.

Photogrammetric analysis

Although no flight recorder was fitted, there was sufficient video of high enough resolution to analyse the aircraft flight path during the demonstration flight, maximum altitude achieved after loss of control and vertical speed at impact.

The AAIB tasked a specialist video forensic examiner to estimate the aircraft position and altitude over time, using photogrammetry. This involved identifying features in the video which could be geolocated using aerodrome survey data and a satellite image of the area taken on the day of the accident. These features can be tracked over time and three dimensional coordinates can then be calculated using video analysis software to calculate the position and orientation of the camera in each video frame.

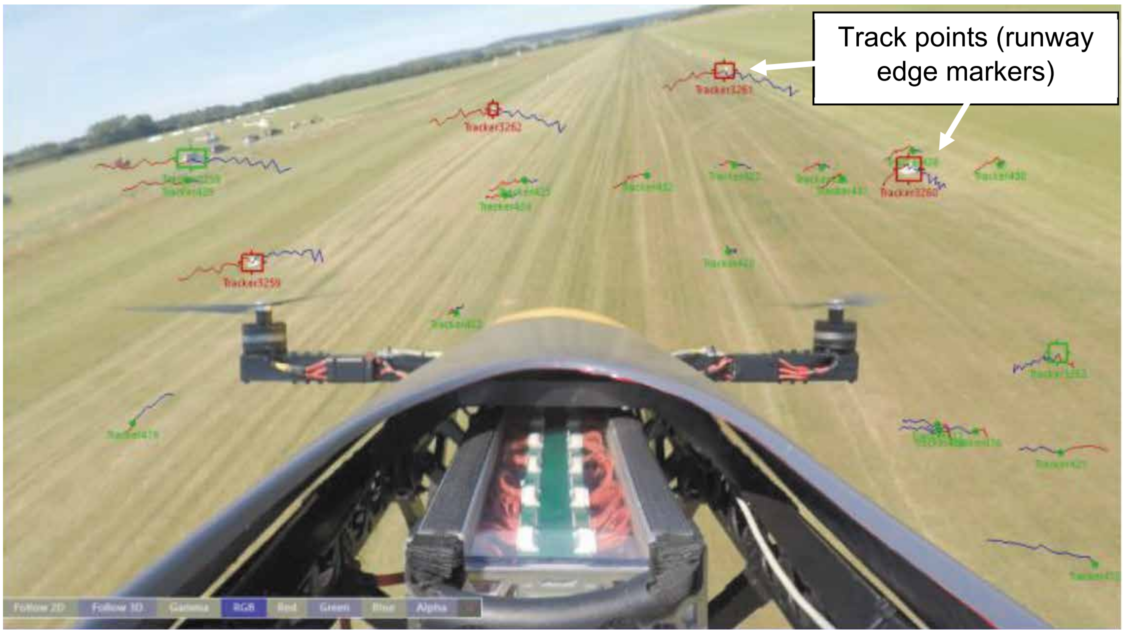

Figure 17

Footage from forward-facing camera showing two of the track points

Takeoff and display until loss of control

After takeoff, the aircraft tracked directly towards the threshold of Runway 32 at low speed, no post-takeoff control check was performed. The display then consisted of a number of runs past the aerodrome building where the aircraft initially pitched down to increased speed, before pitching up again to slow down prior to a turn. Parts of the first and third passes (left to right for the spectators) were performed within the safety buffer zone (Figure 18); the second and fourth passes were within the designated operating area (Figure 16).

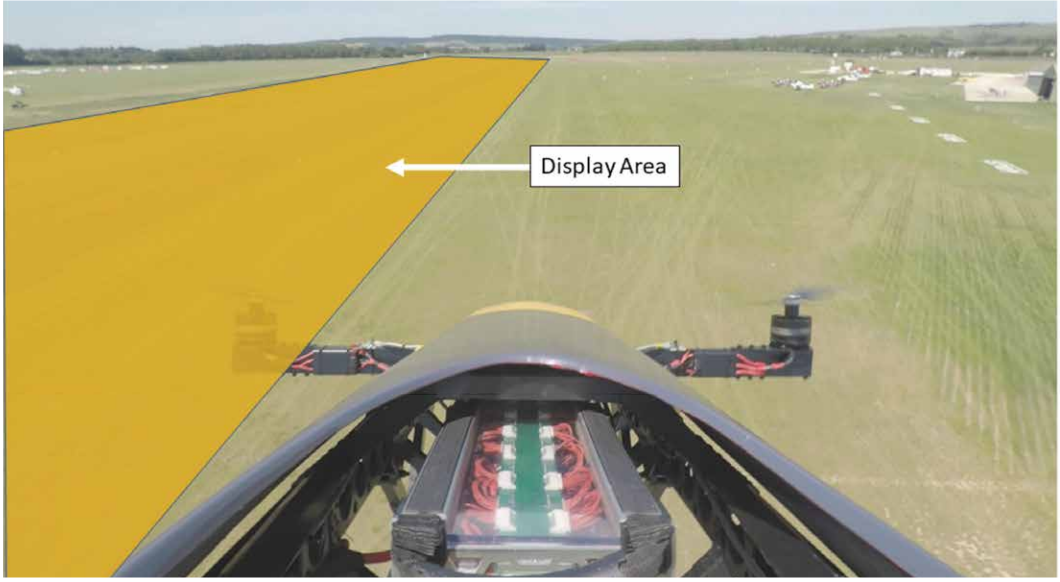

Figure 18

Aircraft on first pass to the east of Runway 32 inside the safety buffer zone

The calculated altitude during the display was within the CAA's exemption limit of 67 ft (20 m) but the groundspeed was in excess of 11 m/s on a number of occasions. The average groundspeed for the display was 12.9 m/s with a maximum of 25 m/s (Figure 19). With the aircraft at 20 m height and 25 m/s, using the CAA's calculations, the aircraft would travel 50 m if the kill switch was activated or power was lost.

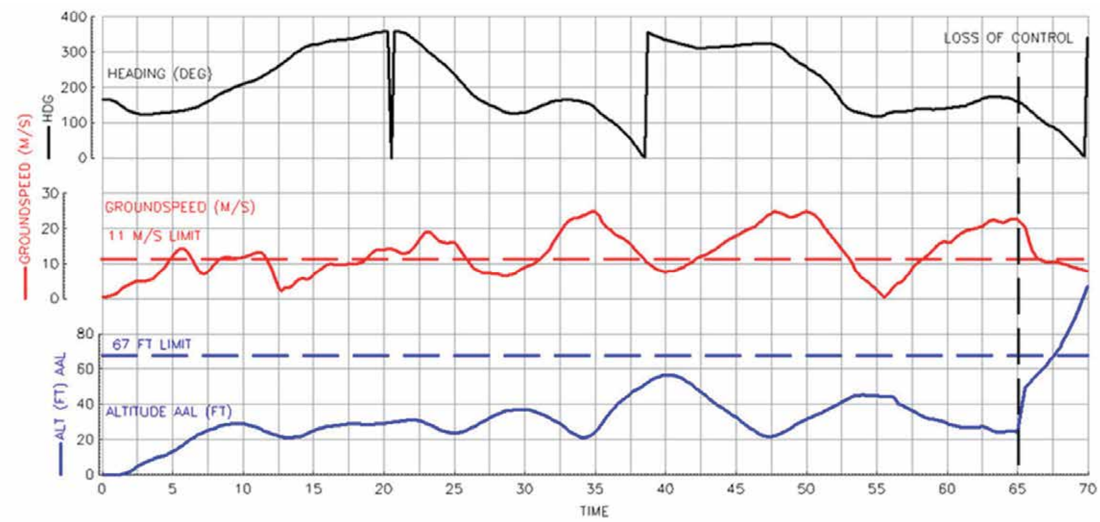

Figure 19

Derived heading, groundspeed and altitude from video analysis

At the end of the fourth pass, as the aircraft began to turn left in a climb, control was lost and the aircraft began the uncontrolled climb. Time elapsed between takeoff and loss of control was approximately 65 seconds.

Climb and loss of signal

As per design, the aircraft continued at its previous throttle setting and with the self-levelling function, began a climb with a yaw rate of approximately 40°/sec. The aircraft climbed, uncontrolled, for 4 minutes 12 seconds, initially at around 2,000 ft/min. The rate reduced towards the top of the climb as the battery became depleted (Figure 20). The accuracy of the altitude estimation decreased as the altitude increased so a precise maximum altitude could not be established. The video analyst estimated this as 7,867 ft with an estimated error margin of ± 750 ft (see also below).

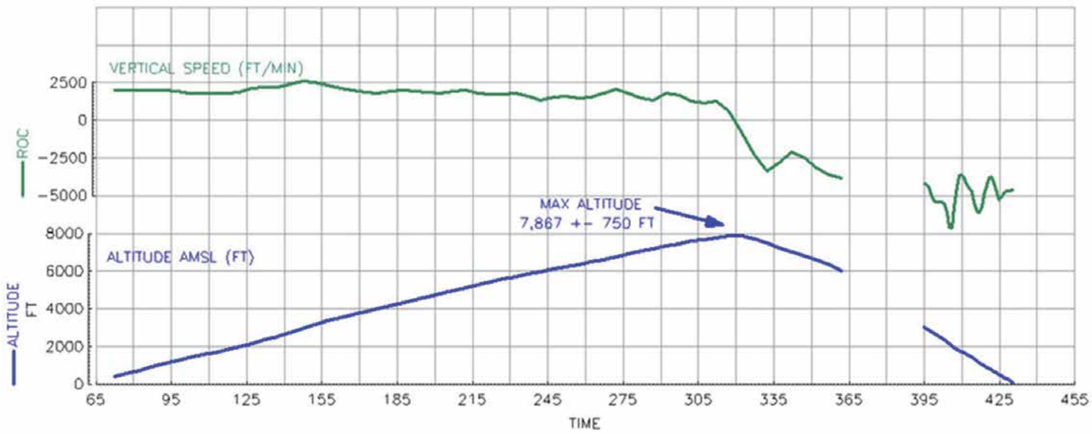

Figure 20

Altitude and vertical speed profiles.
Note gap in the data is where analysis was not performed.

At the top of climb, the bottom camera captured the view over the south coast of West Sussex and Hampshire with the southern coast of the Isle of Wight visible (Figure 21).

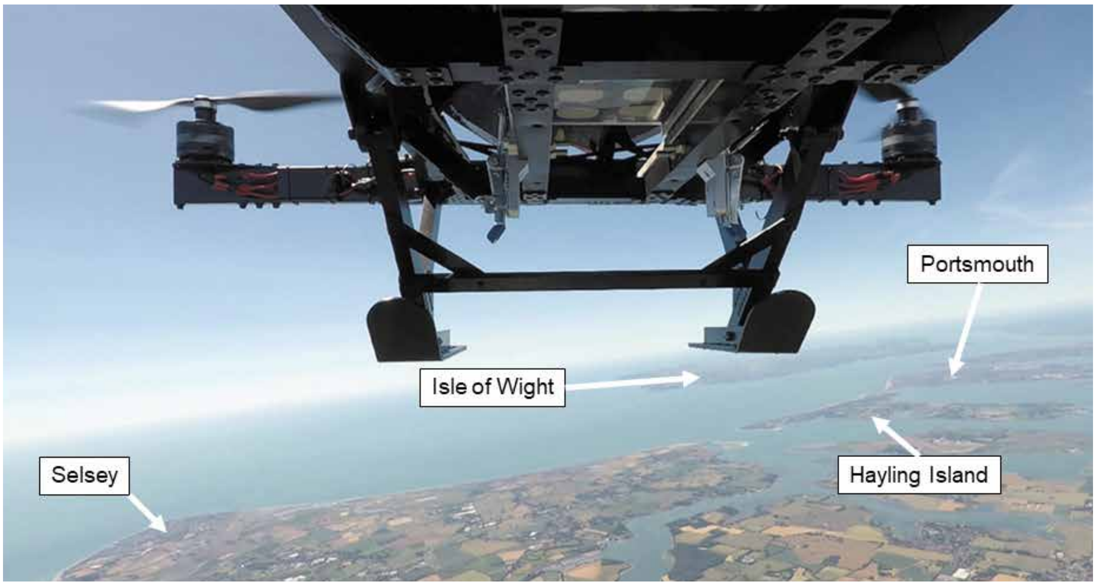

Figure 21

View at apogee from onboard camera

Loss of power and descent

As the battery depleted, the motors slowed, and the aircraft began to lose control with an increasing yaw rate and loss of altitude. This continued until 54 seconds into the descent when the aircraft flipped inverted. The descent continued inverted in a relatively level attitude and slow yaw to the left.

Between 3,000 ft and the impact point, the average rate of descent was 5,000 ft/min and approximately 4,500 ft/min at impact. Due to the relatively benign wind conditions, the aircraft travelled 875 m from the takeoff point with a total flight time of 7 minutes 10 seconds. The kinetic energy at impact with a rate of descent of 4,500 ft/min was calculated as 24,800 Joules.

Accuracy

The large number of trackers, coupled with the detailed survey data of the aerodrome and satellite imagery, gave a high confidence level in the position information derived. For positional accuracy using this technique, previous testing of estimated position to a known aircraft position showed an accuracy of between 2 and 125 m but the test aircraft was at 5,000 ft amsl. Due to the significant number of track points and geo-locatable markers during the low-level display of the accident flight, positional accuracy for this segment was estimated as within ± 5 m.

Altitude estimates were relative to the average height of the tracking points that were in the camera's view. Altitudes in and around the airfield were considered to be more accurate (between 5 to 10 ft) than those estimated with the aircraft at higher altitudes. As the aircraft climbed, the reference features are farther away and dispersed over a wider area. The average track point altitude for the climb segment was 229 ft, ranging from 23 to 491 ft. For altitude estimation, previous testing showed an accuracy of ± 300 ft at altitudes of around 5,000 ft. Given that this aircraft went beyond this, and the variability of the reference feature altitudes, altitude accuracy was estimated at ± 750 ft.

CAP 722 and Airworthiness

Section 4 of CAP 722, Edition 6, was titled '*Airworthiness*' with guidance on certification and the suggested approach for aircraft which did not require certification to formal standards. At the time of the accident, this applied to any UAS with a takeoff mass of between 20 to 150 kg. For this case, the CAA used the OSC process.

While no formal airworthiness requirements were required for this category, the *'General Certification Requirements'* section of CAP 722 stated that:

> *'…it is considered worth noting that elements of the safety case must reflect similar information to that which would be developed within the certification process. It is therefore considered that a level of understanding of the certification requirements may therefore be useful, and maybe beneficial in designing the aircraft, even though not required by the regulatory system.'*

CAP 722 indicated that UAS applications would be scrutinised in a proportional way to the risk its design and usage posed on the general public and their property. If there was a lack of demonstrable airworthiness, risk could be mitigated by operational limitations. As each design was likely to be unique, it stated:

> *'As such, the onus is placed on the operator to understand and describe not just the aircraft design and its capabilities, but also the potential failures of the aircraft and its control systems, the consequence and severity of these and how they are to be mitigated or managed for the operations to be undertaken'*

In addition:

> *'As such, whilst the requirements may not apply, it is recommended that the higher the mass, or the more complex and more capable the aircraft, the more an organisation must refer to the airworthiness requirements that would apply to the next category of aircraft as this could provide useful information on the types of information to be addressed within the safety case.'*

Appendix C of Edition 6 of CAP 722 provided a template and guidance on how to complete an OSC. This was broken down into various sections of which Section 1.1 of OSC Volume 2 was titled '*Details of design and manufacturing organisation(s) and any recognised standards to which the equipment has been designed, built and tested'.*

EASA airworthiness requirements and European Technical Standing Orders refer to standard environmental testing of avionics hardware which, amongst others, includes standards for vibration, temperature and shock. In addition, there are also references to standards for safety-critical software in airborne applications.

Safety assessment

Part 4 of the Airworthiness section in CAP 722 referred to safety assessments and highlights the benefits of using safety assessments as part of the iterative design process. The CAA again takes a proportionate approach to scrutiny, depending on the aircraft in question and detailed safety assessments along the lines expected for certified aircraft are not expected.

There was also guidance on how to produce a safety assessment in OSC Volume 3. This section defined a number of guidelines and definitions of both risk severity and likelihood (Tables 1 and 2).

Severity of Consequences		
Definition	**Meaning**	**Value**
Catastrophic	Results in accident, death or equipment destroyed	5
Hazardous	Serious injury or major equipment damage	4
Major	Serious incident or injury	3
Minor	Results in minor incident	2
Negligible	Nuisance of little consequence	1

Table 1

CAP 722 Risk Severity Classifications

Likelihood of Occurrence		
Definition	**Meaning**	**Value**
Frequent	Likely to occur many times	5
Occasional	Likely to occur sometimes	4
Remote	Unlikely to occur but possible	3
Improbable	Very unlikely to occur	2
Extremely Improbable	Almost inconceivable that the event will occur	1

Table 2

CAP 722 Risk likelihood classifications

Airspeeder Design

OSC Volume 2 did not contain any schematics of the flight control system, the circuit design or any details of the control system software. In addition, the OSCs did not detail any known standards to which the aircraft was designed. Interviews with the operator indicated that there were no other considerations than those documented in the OSC. Evidence provided in OSC Volume 2 Section 1.1 referenced the CASA requirement to submit the aircraft for testing, inspection and assessment (see '*Information from CASA'* section) plus some company details.

The OSC also detailed the installation of a battery and altitude telemetry system, something the CAA had also raised during discussions with the operator. Neither of these systems were fitted for the accident flight.

The aircraft was designed for high speed, high performance operations and the importance of the control systems functioning correctly was reflected in the risk assessment. The flight control circuit boards were mounted on Velcro with a foam lining, in an IP55 box. The circuit boards were not subject to any vibration, shock, RF or temperature testing and the in-house developed software was not developed to any level of assurance.

The construction of the aircraft used a large number of plastic tie-wraps to keep components in place. This included the ESCs, cabling and the connector plates from the control system ethernet cables to the ESCs (Figure 22). Failure of any of these connectors or cables would render the aircraft uncontrollable.

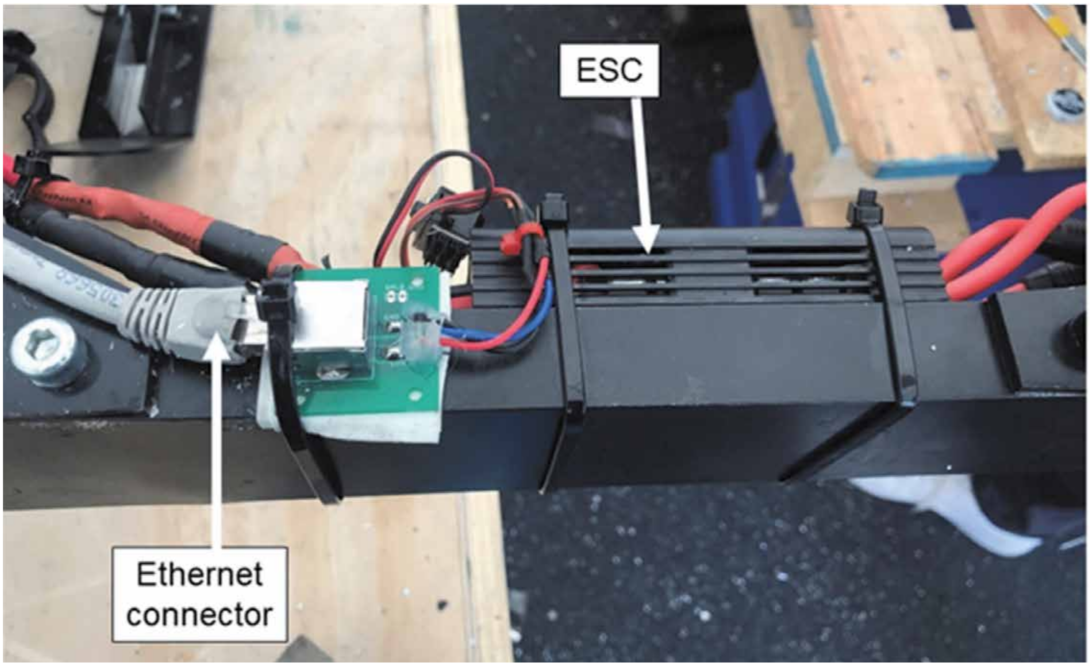

Figure 22
Ethernet cable, connector plate and ESC

Main battery

The battery was developed in-house by the operator who stated that the battery pack was made '*from high impact tolerant polycarbonate and aluminium, inside the case there is a thick foam lining'.* This was expected to provide puncture and impact resistance, but no details were provided on the level of protection this offered. There was no electronic internal safety monitoring for charge, discharge, temperature or open/short circuits.

The battery survived the impact with some visible damage. Upon inspection, the main battery was not placarded with details of battery voltage or the risks it might pose to first responders.

In 2014, EASA issued a Special Condition (SC)[27] to CS-22 for powered gliders with electric propulsion units and associated high voltage batteries. While not required for this application, it provides a useful reference for design and installation of high voltage stored energy devices. It included details of battery management systems, warnings, placards and procedures for reducing the risk to ground personnel.

Footnote

27 SC-22.2014-01 Issue 2.

Single points of failure

The operator identified five items of single point failure which were the ESCs, propellers, motors, flight controller and radio control system. Each of the items was discussed in OSC Volume 2, with information on the primary failure mode of each, along with how this failure mode is mitigated. This involved visual inspection and ensuring each component was operated within its normal design operating range.

For the flight controller, the primary mode of failure was identified as disconnection of cables linking the flight control box and the ESCs. The OSC stated '*To mitigate the risk of signal cable dislodgement due to vibrations or external forces, self-locking Cat-6 cables have been installed on the aircraft'*. This referred to cabling usually used for ethernet connections.

No information was provided on the levels of integrity or assurance of any of the onboard systems. There was no fault tree analysis or system safety assessment. In addition, there was no information on how the flight controller had been designed and manufactured to ensure robustness. The operator was not aware of the failure rates of the components used on the flight control circuit board but had not encountered any failures during testing. The systems were designed so that if there was a component or interconnection failure the system would not work, which could be identified prior to takeoff.

Operator's safety assessment

The operator completed OSC Volume 3 'Safety Assessment' using the guidance provided in CAP 722. A table of hazard identification and risk assessment was provided, listing 22 hazards, risks and mitigation measures. Of these, 16 had a consequence severity of 'catastrophic', which CAP 722 defined as *'Results in accident, death or equipment destroyed'.* One of these hazards was 'Radio Link Failure' with consequence detailed as:

> *'Uncontrolled flight over populous areas, uncontrolled crash, injury or death to spectators and ground crew. Damage to aircraft'.*

The operator defined the likelihood as '*Improbable'*, which CAP 722 defined as '*Very unlikely to occur'*.

The mitigation measures implemented were:

> *'Radio signal inspection of the planned flight path, including the identification of dead spots outside the flight path and, if necessary, amendments to the flight plan. Ultra-long range high power radio links used with a backup link. Kill switch operating on different long range radio frequency. Pilot to fly within flight profile restrictions defined in the Event Flight Plan.'*

It was not stated in this part of the OSC that once the radio link was lost, the aircraft would continue flying using its last known command. There was also no consideration on the effect of the kill switch not operating and the hazard of a 'fly away' case was not considered.

Of the 22 hazards considered, two of those listed were to do with mid-air collisions with other remotely piloted aircraft which was not relevant to this operation. No reference to operating other aircraft at the same time was present in any part of the application.

Part of this OSC Volume 3 was a ‘Self Assessment’ where the applicant was required to detail why they were safe to operate in the described environment. The operator completed this, relying entirely on previous operations in Australia and the accreditations provided by CASA.

Part 3 included a summary of all three OSC volumes, drawing out key elements. This again relied heavily on previous operations in Australia, but the operator also indicated that the Mk II aircraft was a lower risk platform to operate than the Mk IV aircraft:

> *‘In order to showcase this unique aircraft, the chosen platform of flying the ¾ size prototype, which does not exceed speeds of 80kms/hr, over the full size MK4 helps to minimise and mitigate any operational risks to as low as reasonably practicable.’*

They also stated that:

> *‘All materials used are of the highest grade, the finished product passing CASA’s assessment for airworthiness on the first submission.’*

And:

> *‘This aircraft has the following attributes which make it particularly suitable for these types of operations, namely:*
>
> - *Four individually controlled motors/propellers - therefore a large amount of built-in motor redundancy*
> - *Redundant flight control systems and killswitch - therefore a huge level of built-in technical redundancy, greatly reducing the chances of a catastrophic system failure within the aircraft.*
>
> *The list above is not intended to be exhaustive, but highlights a couple of main aspects to consider.’*

According to the operator, the aircraft could not be controlled if one propeller was not working. Although there were segregated systems, they were not redundant systems. Redundant systems offer a degree of backup such that after a failure of part of the system, function can be retained.

OSC Volume 1 contained a section on accident prevention and flight safety. In this section, threat and error management (TEM) was considered and also required as part of the Job Safety Assessment (JSA)[28]. The operator did include ‘loss of control and flyaway’ as part

Footnote

[28] The JSA was a safety assessment performed prior to each operation.

of their TEM but mitigated this with ‘toggle controller options (GPS / Atti / Manual), invoke return to home, radio broadcast’. As no GNSS system or automated safety system was fitted this statement was incorrect.

The JSA performed for this flight was a simple checklist, confirming permissions and operational parameters. One checklist item was ‘*Are spotters needed and if so are locations planned?’* which was marked as successfully completed.

System operation

The flight controller was designed so that if link was lost, it would continue with its last known command, at a level attitude. The operator considered that maintaining the aircraft under this control was a better option than simply cutting power and allowing the aircraft to descend, out of control, until it struck the ground.

In the description of the flight management and control system, it stated that:

> *‘With no input from pilot, the UAV will continue on its current set position as per the four positions of the controller inputs, but will lose altitude gradually and crash land.’*

While this is correct, the description omits to indicate that the aircraft will only lose altitude once the battery depletes after a maximum of 8 minutes of operation. Once the battery is depleted, altitude will then be lost but not in a controlled manner.

There was a common point to both the flight controller and kill switch which was the control system relay. The decision to wire this relay in the ‘Normally Closed’ position was based on ensuring that the flight controller was still available even if the kill switch suffered a failure.

Occurrence reporting

A requirement of the CAA exemption was for ‘*Any occurrence that take place while the said aircraft is being operated under this Exemption shall be reported in accordance with Regulation (EU) No 376/2014 (the Occurrence Reporting Regulation)*’. Guidance material for this regulation stated that persons subject to mandatory reporting are required to notify ‘*within 72 hours of becoming aware of the occurrence*’ and that *‘The circumstances allowing a reporting of the occurrences after the 72 hours deadline shall be exceptional’.*

The operator included a section in the OSC on Mandatory Occurrence Reporting (MOR) and Accident/incident and investigation policy. They stated that:

> *‘All Alauda team members are required to report occurrences given the role of each person is in the capacity of an operator, maintenance crew member, or modifying/manufacturing staff member.’*

For accident investigation, there was no reference to the AAIB and the ATSB was listed as the authority to contact in the event of an accident, including their Australian telephone number. This was also listed in the '*Emergency Procedures*'. It is a requirement under The Civil Aviation (Investigation of Air Accidents and Incidents) Regulations 2018 and Regulation (EU) No 996/2010 to report accidents in the UK to the AAIB.

The CAA did not receive an occurrence report for the hard landing of 3 July. They were present for the accident flight on the 4 July, but the operator did not submit the required occurrence report to the CAA until 21 August. In the 'Reporter's description', it stated:

> *'The Airspeeder was piloted without issue for the first 2 minutes of the demonstration at which time the pilot controls lost contact with the Airspeeder. The pilot and spotters initiated emergency comms and did not activate the kill switch as the Airspeeder had veered over the gathered crowd and this would have been exceptionally dangerous. The Airspeeder climbed in a straight direction before descending back to the ground as the battery life reduced (8 mins total battery life). As the Airspeeder battery life ended the Airspeeder then fell to the ground in a nearby field.*
>
> - *There were no injuries and no property damage reported*
> - *At the time the pilot lost contact with the Airspeeder emergency procedures were initiated which included a member of the crew maintaining VLOS [Visual Line of Sight] with the Airspeeder as it left the aerodrome area, during its climb and until it returned back to the ground. All spectators were moved inside as part of this as a further safety precaution.'*

The operator was contacted after this report was reviewed by the AAIB to ensure the sequence of events had been correctly interpreted. A number of staff had since left the operator and they could not establish the source of this report. Subsequent discussion with the Chief Pilot confirmed that the sequence of events was different to those reported in the MOR. The operator was encouraged to contact the CAA to correct the details of the occurrence report that had been submitted.

Operator's investigation report

The operator was provided a redacted draft copy of the AAIB report in August 2020 to which they responded with a copy of their own investigation report and a spreadsheet action plan of items to follow up. The report contained a list of findings which were:

- *'The pilot lost signal with the aircraft due to a frequency conflict not fully tested in the UK environment, likely due to incorrect radio settings and use of the spectrum*
- *The fail safe kill switch was not robust in nature, did not activate as a defence mechanism and there were no further additional redundancies that could have prevented a flyaway scenario*

- *There were differences as to the equipment and systems used on the MK2 aircraft flown in the demonstration compared to the type approved for flight under the Australian regulator CASA and UK regulator CAA and what had previously been tested*

- *There had been insufficient time and resources to adequately test and stabilise the company's equipment in unfamiliar surroundings and lack of company guidelines to ensure this was a mandatory requirement*

- *The team were all relatively inexperienced with aviation systems, procedures, required documentation and the need to formally understand and adhere to these processes.'*

It also stated the following '*safety message*':

> *'This occurrence highlights the importance of confirming the significance of any unexpected observations during testing and pre-flight checks to minimise the risk of the aircraft flying with an unserviceability or absence of required equipment. Unexpected observations need to be investigated, reviewed, documented and actioned. This event also highlights the negative impact that time and commercial pressures can add in having not conducted sufficient pre-flight testing in a new environment, lack of available resources and not following existing procedures.'*

Safety Management Systems

A Safety Management System (SMS) is an organised approach to managing safety and should identify the responsibilities and accountability of key staff members. It should also document the policy and procedures to manage safety within an organisation. An effective SMS will allow the hazards that could affect an organisation to be clearly identified, assessed and prioritised so that appropriate steps can be taken to reduce the risk to its lowest practical level.

Both the CAA[29] and the CASA[30] provide comprehensive guidance on the implementation and operation of effective Safety Management Systems.

Footnote

[29] CAP 795 Safety Management Systems (SMS) guidance for organisations. https://publicapps.caa.co.uk/docs/33/CAP795_SMS_guidance_to_organisations.pdf (accessed 12 October 2020)

[30] CASA Safety Management System kit for Aviation-A practical guide 2nd edition. https://www.casa.gov.au/safety-management/safety-management-systems/safety-management-system-resource-kit (accessed 12 October 2020)

Other similar events

The CAA reported that as of August 2020, there are over 106,000 registered UA operators in the UK and over 45,000 operators of flying model aircraft.

In November 2019 the CAA launched its '*Drones Reunited*' website to '*help reconnect owners with their lost devices'*. The CAA state:

> *'Drones Reunited will help drone users recover their missing machines - a serious problem for flyers, as new research reveals that over a quarter of drone owners (26%) have lost a drone.*
>
> *The study found that drones are most at risk of being lost due to flight malfunctions - with more than half (51%) of misplaced drones going missing due to battery loss, poor signal, or a technology failure. And in a quarter of cases it's down to pilot error.'*

It goes on to state:

> *'Drones are expensive - costing anywhere from £100 to many thousands - and losing them can really hit owners in the pocket, with many unable to replace their gadget.'*

The AAIB regularly receives accident reports where control of UAS devices has been lost leading to a fly-away or a crash. In AAIB Bulletin 3/2020, five of the seven UAS investigations reported this type of event and Table 4 in AAIB report EW/C2019/03/02 reports 16 loss of control events with one type of UAS in a 20-month period.

Relevant AAIB UAS reports

AAIB report EW/C2019/03/02, published in AAIB Bulletin 1/2020, extensively discusses UAS regulations, both those current at the time of this accident and those implemented on 31 December 2020[31]. In both cases the safety of this type and weight of UAS operation is assured by the regulator approving a safety case and the primary risk mitigation is by ensuring separation from members of the public and property.

This report also discussed the risk of injury due to falling objects and referred to the UK Oil and Gas industry's DROPS[32] analysis tool. It noted that using this tool, a blunt object of around 5 kg (a typical mass of a small UAS) falling from around 3 m could cause a fatal injury. The kinetic energy of this fall would be about 140 joules.

The rules introduced by IR 2019/947 for devices in the open category state that aircraft able to impart 80 joules of kinetic energy shall not be operated intentionally over 'uninvolved people'.

Footnote

[31] EU Commission Implementing Regulation (IR)(EU)2019/947 which is summarised in CAA CAP 1789.

[32] DROPS – dropped object prevention scheme provides an indication as to the possible outcome of a blunt object in free fall striking a person wearing personal protective equipment (ie hard hat, eye protection).

AAIB report AAIB-26314, published in July 2020, investigated an accident involving a DJI Matrice M600 UAS which suffered a '*GPS Compass*' error which resulted in the drone reverting to manual flight mode. By the time the pilot realised the UAS was not responding to the '*return to home*' command the UAS was out of sight. It continued to drift in the wind until it struck the roof of a house, falling into a garden. One Safety Recommendation was 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.

Other relevant UAS events

On 2 May 2020, a 25 kg fixed wing experimental UAV was undertaking a test flight in Latvia when control was lost and a fly-away occurred. As a result, the airspace surrounding Riga International Airport, Latvia, was closed while attempts were made to locate the UA.

The last verifiable information about the UA's location was at 1948 hrs local time, 2 May 2020, 8 hours 20 minutes after takeoff. The UA was subsequently located on 15 May in a tree in a forest. The UA was capable of flying at about 70 km/h (44 mph) and had enough fuel for 90 hours of flight when the fly-away occurred. This event is being investigated by the Latvian Civil Aviation Agency as an '*infringement case*'.

On 27 July 2020 a UA became unresponsive while operating in the Shetland Islands and fell to the ground from 150 ft. It was being used to film a fire that the emergency services were attending. It fell within the cordon, and reportedly narrowly missed a paramedic who was working as part of the response. The weight of the UA and the height from which it fell could have caused fatal injuries had it struck the paramedic. The AAIB and the police are conducting independent investigations.

Analysis

Accident flight

Prior to takeoff the pilot completed the pre-flight checklist. This included a successful functional check of the kill switch. However, the takeoff was 85 m from the point specified in the OSC, Figure 16. Before moving away from the takeoff point, the OSC Volume 1 procedure was for the remote pilot to climb the UA to 1 to 1.5 m agl and carry out checks to confirm that it operated normally. However, video footage of the flight shows that soon after takeoff the UA was immediately manoeuvred towards the threshold of Runway 32 without any of the required checks as to the operability of the aircraft. Had the check been completed it may have identified an issue with the UA and allowed the flight to be aborted.

Prior to the fly-away the UA appears to have been flown under control and at an appropriate height. However, the UA was flown at speeds of up to 25 m/s, in excess of the 11 m/s limit set out in the exemption.

Once control was lost the UA continued to climb, before the motors stopped when the battery became depleted and the UA descended. At the time, the wind at altitude was north-easterly at 8 to 15 kt. Had the wind been of a greater strength there was a significant possibility that the UA would have been blown further downwind over Chichester, where it was more likely to cause third party damage and injury.

The analysis of the onboard video estimated that the UA's apogee was approximately 8,000 ft. Therefore, the UA had entered controlled/Class A airspace that is regularly used as a holding point by commercial aircraft inbound to Gatwick Airport. Following the loss of control, the FISO had informed the UK air navigation service provider (NATS) of the potential for the UA to enter the controlled airspace above the aerodrome. However, the UA still posed a mid-air collision risk to any commercial aircraft routing over the navigation beacon or in the hold at the time, as well as other aircraft that may have been flying in the vicinity of the ATZ.

Design, build and operations

The operator built several prototypes, opting to start with smaller designs and then scale up. Subsequent engineering development relied on trial and error instead of using a focussed development plan using data collected during testing.

Inspection of the UA wreckage and an exemplar UA showed poor quality build and system installation standards. The design and manufacture of the UA did not include the use of any known industry or airworthiness standards and there were no safety systems fitted which could autonomously guide the aircraft to safety in the event of radio link loss, for example a return-to-home function. The circuit boards used in both control systems were of poor quality and build workmanship, and failed to meet any IPC 610A Class. Neither control system was qualified to any industry environmental standard such as impact shock, vibration or temperature.

No onboard recording system was fitted, so the operator was unable to monitor the UA's performance or whether there were any in-flight issues such as intermittent loss of radio link with the kill switch. In addition, the absence of any onboard recording system meant the accident investigation could not establish the exact cause of the loss of control due to lack of evidence.

System operation

The decision by the operator to allow the UA to continue with its last known command after a loss of radio link, was intended to allow it to maintain a degree of stability and control and provide an opportunity for the link to be regained. This decision was not made on the basis of any quantitative safety assessment but in line with their operational procedures, which indicated that the loss of link did not require an immediate kill switch activation to bring the aircraft to the ground. This procedure required people in the vicinity to be moved out of the way and allowed the remote pilot time to attempt to regain control prior to giving the command by radio to activate the kill switch.

While there are advantages to this approach in minimising the damage to the aircraft, it is not a fail-safe option as the aircraft can continue to fly without control. A safer option in this case would have been to activate the kill switch automatically as soon as the radio link was lost. If the aircraft was within the display area it would have struck the ground in a protected and sterile area without needing action by the remote pilot or the observers. Given that the demonstration flight was to take place near a large public event and a large town, this option would have reduced the risk to uninvolved third parties. This would also have been in line with the CAA's expectation that in the event of loss of link, the aircraft could be brought down quickly within the designated areas.

System redundancy

The configuration of the UA meant that in the event of a single rotor, motor or ESC failure, the aircraft would descend, out of control, until it struck the ground. The operator claimed that the kill switch formed a layer of system redundancy. By definition, system redundancy allows a level of backup to allow continued functionality if one system fails. As such, the kill switch offered no redundancy but did offer a segregated system which was capable of making the aircraft safe. The only redundant component in the airborne system was the duplicate IMU which was added after the operator encountered problems during the development phases.

Examples of redundant systems in this case would have been an additional airborne flight controller, additional kill switch, ESCs and/or multiple wiring routes. Levels of redundancy should have been considered during design, based on the likelihood of system failures and their consequences.

The kill switch relay control of the flight controller was wired so that if the kill switch failed, the flight controller could continue to be used. Although this allowed the aircraft to continue flight under control, a failure of the kill switch would only be apparent when an emergency situation required its use. Had this relay been wired in the 'normally open' position, loss of the kill switch would cut power to the flight controller and the aircraft would descend uncontrollably to the ground. Assuming the aircraft was being flown within the sterile display area, this is more acceptable than the risk to the public of a fly-away case of such a large UA.

The CAA recognised the simplicity of the control system design and its lack of GNSS-based safety systems. With this in mind, the sterile area was sized to help reduce risk to third parties by assuming the aircraft could be brought down within the confines of this area.

Failure of airborne control systems

The ground-based components of the control systems were all tested after the accident and found to be operational. The damage sustained to the circuit boards recovered from the airborne control systems had rendered both the flight controller and kill switch inoperative.

Dynamic operation of this large UA, with large propellers and high-powered motors would have generated vibration which may have affected the control system circuitry. The expected levels of vibration were not known by the operator. There were no abrupt or unusual manoeuvres prior to the loss of control that could explain why the flight controller circuit board would fail.

As the control systems were not inspected between the accident of 3 July and the accident flight on 4 July, the condition of these circuit boards was unknown prior to takeoff. If they had been damaged or weakened during the accident of 3 July, it did not affect control of the aircraft prior to and during the initial display at the aerodrome. However, the design of the kill switch meant that it could have failed at any time after takeoff without being detected.

During the course of the investigation the operator demonstrated little knowledge or understanding of appropriate industry standards, in particular, those relating to airworthiness and for developing electronic hardware and software. Therefore, the following Safety Recommendation has been made:

Safety Recommendation 2021-001

It is recommended that Riotplan Proprietary Limited, trading as Alauda Racing, amends its processes to ensure that it designs, builds and tests unmanned and manned aircraft in accordance with appropriate standards to ensure the safety of those who may be affected by their operation.

CAP 722

The regulations published by the European Commission on 11 June 2019 related to the harmonised use of UAS within Europe. These were implemented by the UK Government, with the CAA providing policy and guidance by updating CAP 722 to Edition 8 on 5 November 2020. This accident has highlighted a number of areas where clarification and further information should be provided for the design, manufacture, regulation and operation of UAS.

Risk assessment

The CAA classified risk severity in CAP 722 with anything considered 'Major' or worse being capable of causing injury or death (Table 1). Higher risk operations can pose a safety risk to the public, so the mitigation measures and likelihood of occurrence have to be carefully considered.

Before any mitigation measures, 16 of the 22 hazards identified in the safety case had consequences that were documented in the operator's OSC as potentially catastrophic. These were all discussed in their risk assessment which also considered the likelihood of each risk. Each was given a mitigation which reduced the likelihood and consequence to a level considered acceptable by the CAA. As these mitigation measures relied on airworthy systems, this could not be assured without detailed scrutiny of the design and manufacture of the aircraft.

In CAP 722, Edition 7, the CAA changed the way that it assessed exemption applications, reducing the emphasis on mass, and defining the risk and/or complexity as A (low), B (medium) and C (high). In both versions of CAP 722, the higher assessment case, C, is only invoked when a design is technically complex or operated in a complex environment. This investigation has identified a weakness in this approach in that it requires detailed analysis of UAS which rely on onboard systems to mitigate risks.

Since the accident, the CAA UAS Sector Team has recruited a UAS Technical Inspector with specific background in airworthiness and avionics engineering to increase its in-house capability to assess the airworthiness of specific UA's and systems. Where capability of the UAS Sector Team is limited, measures are being put in place to be able to consult other capability areas within the CAA where required.

A policy has also been developed, which was due to be accredited in the final quarter of 2020, to trigger the involvement of other capability areas within the CAA when the 'in-house' expertise is insufficient. As this policy has not yet been adopted, the following Safety Recommendation is made:

Safety Recommendation 2021-002

It is recommended that the Civil Aviation Authority update Civil Aviation Publication 722, Unmanned Aircraft System Operations in UK Airspace – Guidance & Policy, to require detailed evaluation of any Unmanned Aircraft Systems that use onboard systems to mitigate risks with Risk Severity Classifications of 'Major', 'Hazardous' or 'Catastrophic'.

Radio frequency interference

The operator indicated that they had never had radio link problems with this aircraft. They stated that the 'signal strength test' had been successfully completed the day before the accident flight but this did not involve using the kill switch or any supplementary electronic equipment such as a spectrum analyser. CAP 722 did not require the use of a spectrum analyser, only referring to its use if an aircraft is used in an urban environment.

The kill switch frequency and communication protocol were different to that of the flight controller. This was confirmed as being operational prior to the flight but, given that no radio survey was performed with the kill switch, its operation in the display area could not be confirmed. As the flight progressed, with no two-way communication with the kill switch, its operation could not be assured until it was activated.

The OSC did not define any detail of the signal strength test, only that it had to be performed. As the effect of loss of signal to the flight controller was for the aircraft to continue flying, there was a strong reliance on the kill switch being available to ensure safety.

The safety case identified the consequence of the radio link failure as one which could potentially result in an accident, death or equipment destruction. The mitigation measures included the 'Radio signal inspection of the planned flight path' which, in practice, did not include use of the kill switch.

Previous AAIB investigations have identified cases where unmanned aircraft have lost control and flown-away. The CAA's Drones Reunited website stated that one reason for UAs going missing was due to 'poor signal'. In this case, the reliance on the radio link to operate the kill switch required close scrutiny to identify the likelihood of RF interference and the potential for 'poor signal'.

To ensure that UAS operators carefully consider radio surveys as part of their pre-flight preparations, further emphasis should be included in CAP 722 to ensure UAS operators carefully consider radio surveys as part of pre-flight preparations. The CAA UAS Sector Team have requested that guidance material detailing possible methods to prove that the RF link between the UA and controller is secure be added to the next version of CAP 722. As this action has not yet been confirmed or completed, the following Safety Recommendation is made:

Safety Recommendation 2021-003

It is recommended that the Civil Aviation Authority update Civil Aviation Publication 722, Unmanned Aircraft System Operations in UK Airspace – Guidance & Policy, to provide guidance on the planning, completion and documenting of Radio Frequency surveys to reduce the risk of Radio Frequency interference or signal loss when operating Unmanned Aircraft Systems.

Additionally, the UAS Sector Team have requested that the next version of CAP 722 include a requirement for the applicant to prove and provide evidence of a secure RF. If an RF survey has been stated as a mitigating factor to reduce the risk of a "poor signal" related failure, or to support the use of an RF-enabled safety system, then proof of example surveys will be requested as part of the approval process. On a case-by-case basis, the UAS Sector Team will also request these documents before issuing an approval.

As this action has not been confirmed or completed, in order to ensure that safety systems fitted to a UAS which rely on a radio link for their operation will not be subject to Radio Frequency interference and/or loss of signal, the following Safety Recommendation is made:

Safety Recommendation 2021-004

It is recommended that the Civil Aviation Authority require Unmanned Aircraft System operators, that use unmanned aircraft which rely on a radio link to operate safety systems, to provide Radio Frequency survey reports to the Civil Aviation Authority for review, to ensure they are suitable and sufficient.

Display area

With the aircraft maintaining the speed limits within the CAA's exemption, completion of the 'loss of link' procedure would have to have been rapid in order to ensure the aircraft was brought down within areas designated in the OSC. If the aircraft was at the eastern edge of the display area, travelling at 11 m/s and 20 m agl, when kill switch activation was required, a reaction time of 2.1 seconds or less would be needed to maintain the aircraft in the safety buffer zone, and 4.8 seconds or less to prevent the aircraft from potentially hitting the viewing platform.

The operator's trajectory calculations suggested that they expected the aircraft to travel no more than 22 m and impact the ground within 2.02 s. While not detailed in the OSC, this was within the 30 m limit that they proposed. The calculations did not consider any reaction times or tolerance on the exemption limitations. At 25 m/s (maximum estimated speed on the accident flight), with no reaction time, the aircraft would have travelled 50 m, more than the width of the safety buffer zone, before striking the ground.

The OSC defined the display area using the eastern edge of Runway 32 as its boundary, using Google Earth imagery from 2015. As a consequence, the display area was 15 m narrower than the pilot may have been expecting. Analysis of the flight path indicated that some of the display was performed within the safety buffer zone on this eastern edge of the runway.

The definition of UAS operational and safety areas relies on the use of accurate mapping or imagery together with trajectory calculations which take into account human or automated safety system reaction times and the UAS' maximum speed and altitude. CAP 722 does not contain any guidance on how operational and safety areas should be defined. Therefore, the following Safety Recommendation is made:

Safety Recommendation 2021-005

It is recommended that the Civil Aviation Authority update Civil Aviation Publication 722, Unmanned Aircraft System Operations in UK Airspace – Guidance & Policy, with guidance on how to define an Unmanned Aircraft System's operational and safety areas, using up-to-date maps, accurate trajectory analysis and human or automated safety system reaction times, to ensure a safe operation.

Safety systems

A number of modern commercially available UAS are fitted with GNSS position monitoring systems as standard which can aid navigation but also enable electronic safety measures. These include geo-fencing, automated return to the takeoff point, controlled descents, hovering and automatic landing. Other safety systems are also available including automatic parachute recovery systems which, on detecting a problem, shut off the UA's power supply and deploy a recovery parachute. This UA contained no such systems, relying only on a simple kill switch to cut power and allow the aircraft to descend to the ground uncontrollably in the event of emergency.

The use of any of these safety systems on the UA could have significantly reduced the risk to other aircraft and the public. Given that the CAA will receive other applications for exemptions for unique or novel designs in the future, the incorporation of such safety systems may be a significant factor in assuring appropriate levels of safety.

CAP 722 does not require the installation of safety systems or detail any examples of safety systems. In addition, not all UAS operating with an exemption to the ANO or an Operational Authorisation[33] are required to be fitted with safety systems. The use of such systems provides additional protection in the event of a malfunction of the UAS and so the following Safety Recommendations are made:

Safety Recommendation 2021-006

It is recommended that the Civil Aviation Authority update Civil Aviation Publication 722, Unmanned Aircraft System Operations in UK Airspace – Guidance & Policy, to provide examples of Unmanned Aircraft System safety systems.

Safety Recommendation 2021-007

It is recommended that the Civil Aviation Authority introduce requirements to define a minimum standard for safety systems to be installed in Unmanned Aircraft Systems operating under an Operational Authorisation, to ensure adequate mitigation in the event of a malfunction.

Demonstrating compliance with the exemption

This investigation identified a number of non-compliances by the operator to the CAA's exemption, Appendix A. Those relating to the geographical and speed limitations had to be calculated after the accident using photogrammetry from on-board video.

The aircraft was not fitted with a data recording system. Such systems provide significant benefits during the design and development of a UAS as well as to accident and incident investigation. In addition, recorded data could be used to demonstrate the maturity and suitability of the UAS for the operation and compliance with the conditions of an Operational Authorisation. Therefore, the following Safety Recommendation is made:

Safety Recommendation 2021-008

It is recommended that the Civil Aviation Authority require Unmanned Aircraft System operations under an Operational Authorisation to be fitted with a data recording system which is capable of demonstrating: compliance with the Authorisation's conditions, safe operation and the logging of any failures which may affect the safe operation of the Unmanned Aircraft System.

High-voltage stored energy devices

The first responders to this accident were presented with the wreckage of a large UAS which had no external markings other than the sponsor's names. The damaged main battery was hazardous but there were no warnings of the risks of explosion or electric shock. There was also no battery self-monitoring system for temperature or voltage. As

Footnote

[33] After 31 Dec 2020 the exemption to the ANO will be replaced by an Operational Authorisation.

use of such batteries is likely to become commonplace in large UAS, the following Safety Recommendations are made:

Safety Recommendation 2021-009

It is recommended that the Civil Aviation Authority specify the minimum requirements for the monitoring of Unmanned Aircraft System high-voltage stored energy devices, to ensure safety of operation.

Safety Recommendation 2021-010

It is recommended that the Civil Aviation Authority specify the minimum requirements for readily identifiable warnings and safety information on Unmanned Aircraft high-voltage stored energy devices to inform 3rd parties of the potential hazard.

Organisational observations

The operator defined three accountable personnel in their OSCs: the CEO, Chief Pilot and Maintenance Controller. The CEO was ultimately responsible for all operations conducted by the operator but some of these responsibilities had been delegated to other company personnel.

The remote pilot was the operator's Chief Remote Pilot and their only pilot that was authorised to operate the aircraft. As stated in the OSC, he was responsible for all operational matters affecting the safety of operations, including ensuring that operations were conducted in compliance with the CAA and hence the limitations laid down in the exemption. This made him ultimately responsible for the conduct of the flight and ensuring that the limits of the exemption, as well as those in the OSC, were complied with. However, several limits stated in the exemption and the OSC were not complied with.

He was also responsible for developing checklists and procedures relating to flight operations. Some of these were not adhered to which resulted in a degradation in the safety of the whole operation. Other company personnel did not highlight procedural non-compliances.

The maintenance controller was responsible for ensuring the maintenance of the UAS in accordance with the manufacturer's specifications. His roles and responsibilities included recording and investigating all significant defects in the UAS. The incident of the 3 July was investigated but the re-use of safety-critical components from this incident may have been contributory to the subsequent loss of control on 4 July.

Each flight was internally approved by the operator, using their 'Flight Approval Form' which was signed by the CEO and Chief Remote Pilot. This form included the task description and all the limitations to which the aircraft was to be flown and was included as an Appendix to OSC Volume 1.

All the operator's OSC volumes were authored by the CEO's 'Executive Assistant' (EA) who also managed the exemption application with the CAA. Each OSC was signed by the EA but not by the CEO, Chief Remote Pilot or Maintenance Controller. Between 14 April 2019 and 2 July 2019, there were at least six versions of each OSC volume and although the accountable positions may have been aware of the changes, the absence of countersigning meant that this could not be confirmed.

The OSCs represented the operator's most important documentation in the exemption application but contained a number of inaccuracies and misrepresentations. The process to release such important documentation did not involve a counter-signatory, sufficient scrutiny or a robust process for accountable members of staff to check it.

The operator did not have a Safety Management System in place. Their lack of consideration for compliance, quality control and safety contributed to this accident. In addition, the absence of internal oversight, cross checking and management by accountable personnel were key factors and demonstrated that the organisation did not have an effective, proactive approach to managing safety. Safety management extends beyond compliance with regulations to a systemic approach to the identification and management of safety risks. Both the CAA and the CASA provide comprehensive guidance on the implementation and operation of effective Safety Management Systems. Therefore, the following Safety Recommendation is made:

Safety Recommendation 2021-011

It is recommended that the Civil Aviation Authority ensure that operators of Unmanned Aircraft Systems have an effective Safety Management System in place prior to issuing an Operational Authorisation.

The operator stated that, as a result of the accident, they have carried out a comprehensive review of their operation and, as a result, have introduced a Safety Management System in line with the guidance material published by CASA.

Operator's OSC

The extant CAP 722 contained references encouraging organisations to understand certification requirements and that aircraft of a higher mass would be expected to refer to requirements of aircraft in a higher category. The absence of this information in the OSC's should have alerted the CAA to the limited aviation experience of the operator.

The OSC was prepared for the sole purpose of the demonstration flights at Goodwood in July 2019. However, it contained inaccuracies; for example, Volume 1 stated that any accidents or incidents should be notified to the ATSB rather than the AAIB, as the UK's safety investigative authority.

The OSCs did not reference any certification or industry standards that the aircraft was designed and built to. The section in the OSC requiring '*Details of design and manufacturing organisation and any recognised standards to which the equipment has been designed, built and tested*' contained reference to CASA requirements. There were a number of other references to the scrutiny and oversight by CASA which the CAA did not corroborate.

There were no schematics, photographs or wiring diagrams provided for the control systems, nor did the CAA require evidence of this. Had this been included, it could have revealed exposed wiring, low quality circuit board build standard and use of prototyping circuit boards.

The operator detailed in their OSC that the Mk II was a lower risk platform to operate than their proposed Mk IV. However, the proposed Mk IV's takeoff mass of 250 kg would have required a full EASA certification, as well as qualified personnel in accountable manager positions.

CAP 722 also indicated that the onus was on the operator to identify potential failures, their consequences and means of mitigation. The rationale for this was that, as designs were likely to be unique, the operator would be best placed to identify likely failure scenarios. In this case, the operator did not consider a total loss of radio link for both radio control systems as this was considered improbable. As the loss of link with the flight controller would lead to continuation with the last known command, the subsequent failure of the kill switch would clearly result in a fly-away case.

For the '*Radio link* failure' case, prior to considering any mitigation measures, the consequence was defined as having a potentially catastrophic outcome with a likelihood of 'Improbable' (very unlikely to occur). The mitigation measures included the radio signal strength test, use of high strength radio links and the separate kill switch system. The reliance on the correct operation of the kill switch therefore relied on a robust design and manufacture of this system.

The investigation identified several issues with the design and build of the aircraft, including a lack of redundancy, the use of cable ties to secure flight critical components and the lack of vibration protection of vital components and a lack of safety features.

While the CAA places the onus on the operator to identify failure cases, the CAA has an important role in oversight to properly assess an organisation's ability to identify such failure cases and any mitigation measures.

CAA Exemption process

The accident aircraft and the organisation who designed, manufactured and operated it were previously unknown to the CAA. Although the application for an exemption had been received by the CAA a few weeks before, the technical evaluation commenced on the 19 June 2019 in anticipation of flights on the 3 to 7 July 2019. After a detailed review by the UAS Unit, using the CAA's OSC checklist, they held an informal 'peer review' meeting with a member of the UAS Policy team to discuss areas of concern. This person had considerable experience in airworthiness and identified a number of concerns about the application. There were no formal actions from this meeting nor a record of what was discussed internally. Given the importance of the peer review in highlighting areas of concern, formalising and recording these meetings and subsequent actions would have provided useful evidence that could be referred to when considering the granting of an exemption. A list of points for clarification was sent to the operator and they returned an amended copy of the OSC.

The OSCs contained reference to approvals that claimed to have been issued by the Australian regulator, CASA. The CAA had attempted to contact CASA, but when a reminder was sent on 29 June 2019, CASA replied that they would need the operator's permission to release data. The CAA decided to base their assessment and the resulting mitigations solely on the information they had been provided by the operator. Had the CAA pursued the CASA references in further detail it would have become clear that the OSCs contained misrepresentations.

Exemption

The CAA indicated that in communications prior to the exemption being issued, they made it clear to the operator that there would be operational limitations. For the display at the aerodrome, the aircraft had to be operated (amongst other things):

- *'at least 30 m from persons, vessels or structures*
- *no further than 150 m from the remote pilot*
- *at a maximum speed of 11 m/s'*

However, the wording in the exemption appeared to make the speed and operating distance conditional on the requirement to operate within 30 m of persons, vessels or structures.

While the CAA seemed confident that the operator understood the conditions and limitations of the exemption, the exemption wording was not considered clear and the conditions could have been presented unambiguously to reduce the chances of confusion or misinterpretation.

CAA oversight

CAP 722 details that, as designs are likely to be different, the CAA adopts a proportional approach to oversight of exemption applications. The level of oversight, processes and procedures adopted by the CAA for granting an exemption for this aircraft and its operation proved to be inadequate.

The CAA recognised that the UAS was relatively unsophisticated in its design, had no redundancy and multiple single points of failure. The number of inconsistencies, misrepresentations and omissions in the operator's OSCs was a missed opportunity that could have alerted the CAA to examine the application in more detail. This may have confirmed the applicant's understanding of the regulations, their competency to identify the potential risk of failure cases and to identify where additional supporting information was needed to accurately reflect the design and manufacture of the UAS.

The exemption was issued by the CAA on the 3 July 2019. The operator arrived in the country five days prior to this, during which time they were still in the process of liaising with the CAA. The CAA did not carry out a physical inspection of the aircraft or meet with the operator before granting the exemption. They were therefore unable to check the aircraft build quality or operation of the safety systems and confirm that additional systems for altitude and battery telemetry, that the CAA had requested, had been fitted.

This operator was new to the CAA and although their OSC contained a number of processes and procedures, several of these were not adhered to on the day of the accident and the accident flight, prior to the loss of control, did not comply with the conditions of the exemption.

Performance Based Oversight relies on previous experience of an operator or aircraft to allow an accurate assessment of the operational risk. As the CAA had not had previous experience with either the operator or the UAS, they did not have any information, other than that supplied by the operator, on which to assess the safety of the operation. A physical inspection of the UAS, prior to granting the exemption to the ANO, would have provided the opportunity to identify the shortcomings in the UA's build standard and that it was not compliant with the OSC. Had the CAA required a demonstration of the aircraft's operation, the operator may have been more vigilant in ensuring that they complied with their own procedures and the conditions of the exemption to the ANO. In addition, it would have allowed the CAA to confirm the operator's credentials and their ability to comply with operational requirements. As a result, the following Safety Recommendation is made:

Safety Recommendation 2021-012

It is recommended that the Civil Aviation Authority, before issuing an Operational Authorisation to operate an Unmanned Aircraft System they have not previously had experience with, carry out a physical examination of the Unmanned Aircraft System to ensure that it is designed and built to suitable standards, and observe a test flight to confirm operation in accordance with the Operating Safety Case.

Compliance with exemption

The exemption listed a number of specific limitations, along with the requirement to operate in accordance with OSC Volume 1. During the flight display, the aircraft was operated within 150 m of the remote pilot and below the height limit of 67 ft. However, during this phase of flight, the estimated maximum aircraft speed of 25 m/s was in excess of the declared maximum aircraft speed (80 km/h (22 m/s)) and more than double that limited by the exemption (11 m/s).

Once control of the aircraft was lost , it climbed to approximately 8,000 ft, Beyond Visual Line of Sight (BVLOS), so the remaining geographical boundary limitations were then exceeded.

The exemption also required the operator to submit occurrence reports in the event of an accident within 72 hours. No report was submitted for the hard landing accident on 3 July and the report for the accident flight was submitted on 21 August, 48 days after the event. The sequence of events reported differed considerably from those confirmed by the remote pilot. The reasons for this difference could not be established but a number of the operator's employees had left the company during the course of this investigation. The CAA did not follow up the occurrence report, deciding instead to wait for the results of the operator's report and the AAIB investigation.

Due to the simplicity of the control system design, there were no automated systems to allow the aircraft to remain within the constraints of the exemption. The OSC indicated that the aircraft was capable of speeds of up to 80 km/h (22 m/s), but there was no speed limitation system or speed display for the remote pilot.

The pilot had practised the display sequence in Australia but had at no point measured the aircraft speed. The aerodrome was a large, open space and judging a speed limit of 11 m/s during a highly dynamic display would have been extremely difficult. Aircraft speed is particularly important as it has a significant effect on any kinetic energy and trajectory analysis. The operator's website and launch presentation at the public event portrayed the aircraft as one being designed to race in an elite racing series. With most of the invited guests being members of the press, there would probably have been significant pressure on the operator's personnel to provide the best possible display of the UA's capabilities.

The aircraft was not fitted with the altitude and battery reporting systems as requested by the CAA and documented in the OSC. The OSCs indicated that each spotter would have a separate kill switch and that a spare flight control transmitter would be available. During the accident flight only one kill switch was available, and the spare flight control transmitter remained in the operator's workshop.

The flight controller transmitter was using a lower transmitter power (10 mW) than that indicated in the OSC (25 mW). This was also a power 100 times lower than had been used for all previous flights in Australia. Ofcom confirmed that other transmitters can use 915 MHz and that this frequency is one also licensed for use by mobile phone network providers. It was also confirmed that this frequency was not permitted for airborne applications. The operator inferred in their OSC that they had examined the UK regulations but did not contact Ofcom for clarification.

On the day of the flight, locations of the aircraft takeoff position, remote pilot and spotters did not meet the requirements of the OSC and only one of the three spotters was equipped with a kill switch. With no spotter located 150 m from the remote pilot, there was no way to confirm this limitation although this was achieved by pilot judgement on the day. No post-takeoff control check was performed and some of the display was performed within the safety buffer zone.

In this accident, the absence of the altitude and speed reporting systems meant that there was no way for the operator to demonstrate compliance with the exemption. Had the flight progressed successfully, the CAA would not have known about the non-compliant operation of this aircraft. Had the operator been required to demonstrate compliance with the conditions of the exemption to the ANO they may have taken all the steps required to ensure it.

The CAA did perform audits on operations and check compliance to exemptions but only for more complex operations. Edition 8 of CAP 722 now gives details of the duty of an applicant for an Operational Approval to maintain suitable operational logs and make them available to the CAA on request. The UAS Sector Team have increased the number of requests that are made to present appropriate logs files, maintenance records, telemetry and other files when completing renewal audits.

CAP 722 and the CAA exemption documentation did not contain any information on the consequences of non-compliance and the action that organisations such as the CAA and Ofcom can take in the event of a breach of the regulations and requirements. Had the operator been cognisant of the potential consequences, they may have taken the required measures to ensure that the aircraft and its operation met the requirements of the exemption to the ANO and other UK regulations. Therefore, following Safety Recommendation is made:

Safety Recommendation 2021-013

It is recommended that the Civil Aviation Authority update Civil Aviation Publication 722, Unmanned Aircraft System Operations in UK Airspace – Guidance & Policy, to include reference to the consequences of not complying with the conditions of an Operational Authorisation to operate an Unmanned Aircraft System.

CAA on-site

The CAA attended the event with the expectation that they would be able to meet the operator for the first time and inspect the aircraft prior to the demonstration flight. However, the exemption was not conditional on this inspection nor did the CAA have any specific inspection criteria or any specific issues they wanted to raise with the operator. The airfield NOTAM was time limited and the CAA were advised that they would not be able to view the aircraft prior to the demonstration flight. Upon arrival, they were directed to the hospitality area, which they agreed to, to prevent interrupting the operators who were concentrating on their pre-flight checklists. Had a structured inspection of the UAS, prior to flight, been carried out it could have easily identified that the UA did not meet the requirements of the exemption to the ANO. Monitoring of the operator's preparations for the flight would also have made it possible to identify that the operator's personnel were not in the correct locations to ensure the safe operation of the UA.

Public Safety

The regulations in place at the time of this accident, and those due to come in to force in December 2020, do not specify build or reliability standards for this size of UA. The regulations assume that a UA will operate as intended and will be able to comply with any operational limitations imposed, to ensure safety. The evidence shows that this is not the case and there are many occasions when reports record a fly away, loss of control, power system failure or mechanical failure.

The CAA's *Drones Reunited* website stated:

'Drones Reunited will help drone users recover their missing machines - a serious problem for flyers, as new research reveals that over a quarter of drone owners (26%) have lost a drone.

The study found that drones are most at risk of being lost due to flight malfunctions - with more than half (51%) of misplaced drones going missing due to battery loss, poor signal, or a technology failure. And in a quarter of cases it's down to pilot error.'

According to this data, over 13% of UA operators have experienced a technical loss of control resulting in a lost UA. As of August 2020, there were over 106,000 registered UA operators in the UK and therefore these figures suggest that there have been at least[34] 13,800 UAs that have landed in an uncontrolled manner or crashed.

An uncontrolled UA represents a hazard as the DROPS research into potential injury from falling objects reported in AAIB EW/C2019/03/02 highlights. It noted that using this tool, a blunt object of around 5 kg (a typical mass of a small UAS) falling from around 3 m could cause a fatal injury. The kinetic energy of this UA would be approximately 140 joules. The accident UA crashed with an estimated kinetic energy at impact of 24,800 joules.

The rules introduced by *Commission Implementing Regulation (IR) (EU) 2019/947* for UAs in the open category state that aircraft able to impart 80 joules of kinetic energy shall not be operated intentionally over 'uninvolved people'.

Constraining the area of a UAS' operation does not provide protection to the public when there is no guarantee that a UA will remain within these confines. In this case the UA entered controlled airspace used by commercial aircraft and it could have crashed in a nearby densely populated area or at a large public event, both with a high potential for fatalities. As there was no control or influence over where it crashed, it was only down to providence that it crashed in a field 40 m away from occupied houses.

The frequent reports of UAS loss of control and fly-away events indicates the potential hazard to uninvolved persons. The kinetic energy level of these impacts, even for a typical small UA, is likely to be well above the 80 joules of kinetic energy limit for a UAS operated intentionally over 'uninvolved people', set in EU Commission Implementing Regulation (IR) (EU) 2019/947, and would typically be at levels where fatal injuries could occur. This UA crashed with 24,800 joules of kinetic energy and had it crashed in a populated or congested area, it is likely there would have been fatalities. It would be prudent to take appropriate action to reduce the risk of this type of event to avoid a fatal accident. Therefore, the following Safety Recommendations are made:

Safety Recommendation 2021-014

It is recommended that the Civil Aviation Authority adopt appropriate design, production, maintenance and reliability standards for all Unmanned Aircraft Systems with aircraft capable of imparting over 80 joules of energy.

Footnote

[34] A UAS operator may have lost more than one UAS and there may be other events where there has been a technical loss of control but the UAS has been recovered by the operator.

Safety Recommendation 2021-015

It is recommended that the European Union Aviation Safety Agency adopt appropriate design, production, maintenance and reliability standards for all Unmanned Aircraft Systems with aircraft capable of imparting over 80 joules of energy.

Conclusions

After the Airspeeder Mk II failed to respond to control inputs it entered an uncontrolled climb at maximum power. Operation of an independent kill switch had no effect and the aircraft continued to climb for 4½ minutes, drifting with the wind and reaching a height of approximately 8,000 ft. The aircraft infringed controlled airspace over a radio navigation beacon used as a holding point for Gatwick Airport. After depletion of the batteries, the aircraft fell to the ground in a field, 40 m from occupied houses and 875 m from its launch point. The operation of the Airspeeder Mk II during the accident flight breached conditions of the exemption granted by the CAA for the flight.

The loss of control was caused by a loss of link between the ground and airborne control systems. The exact reason for this could not be established but considered likely to be either RF interference or a failure of the onboard control system.

The investigation identified a wide range of contributory factors that set the conditions for this occurrence and made an accident more likely.

The Alauda Airspeeder Mk II was not designed, built or tested to any recognisable standards and although the operator's OSC, submitted to the CAA claimed it had been built to 'the highest standards', none were referenced.

A number of issues were identified with the design and build of the Airspeeder Mk II, including numerous single point failures. The assembly of the electronic flight control system failed to meet relevant standards. The flight control system was not capable of providing telemetry to the remote pilot and was not fitted with a GNSS position monitoring system which could have enabled electronic safety measures, such as automatic return to takeoff point or geo-fencing, to be used. There was no placarding to warn first responders of the hazards of the high voltage stored energy device (battery). The Airspeeder Mk II did not have any data recording devices fitted, which would have provided useful information about the conduct of the flight.

The electronic kill switch was manually operated. In the event of a loss of control the remote pilot would have to recognise that the UA was no longer responding to control inputs then communicate with the observer who would then activate the kill switch. The time delay in recognising a loss of control and operating the kill switch could result in the UA descending uncontrollably outside of the specified operating area.

A radio survey of the operating area was conducted for the flight controller, but it was not carried out for the kill switch, which operated on a different frequency. The radio frequency used for the flight controller was not permitted to be used for airborne applications.

A flight, on the day before the accident flight, resulted in a heavy landing when power was lost which was not reported to the relevant authorities. The power loss was due to a faulty battery connector. The flight control unit from this airframe was then transferred to accident airframe without any detailed inspection.

Statements made by the operator and the findings of this investigation showed that they did not appear to have any knowledge or understanding of airworthiness standards.

The operator's OSC provided the basis for the exemption issued by the CAA but systems specified in the OSC for the remote pilot to monitor battery condition and altitude were not installed. The map image used by the operator to define the operating area and safety zone was out of date and it did not accurately represent the dimensions of the runway that was being used as a reference point.

The safety zone defined by the OSC and the maximum operating speed specified by the exemption did not consider reaction and communication times of the operator's staff. The aircraft was unable to transmit telemetry to the remote pilot, so there was no means of monitoring the speed or height of the UA or ensuring that it remained within the limitations of the exemption.

Several areas were identified where CAP 722 could be improved. For instance, there is currently no requirement for UAS to be fitted with GNSS-based safety systems, data recording equipment or warning placards for high voltage stored energy systems to be installed. CAP 722 does not contain any guidance on how operational and safety zones should be defined.

The CAA UAS Sector Team were relatively new to the role and had limited experience in dealing with airworthiness matters. As a result, no assessment was made of the operator's ability to properly complete the OSC and no independent corroboration of information provided by the operator in the OSC was carried out. The OSC contained references to approvals granted by CASA which were not validated by the CAA UAS team.

No face-to-face meetings were held between the CAA and the operator. The CAA did not inspect the UAS before flight or observe a flight before granting the exemption. The CAA arrived 45 mins before flight without prior arrangement to view or inspect the UAS. Their request to inspect the UAS was declined by the operator as pre-flight preparations were already underway and the NOTAM closing the aerodrome to other traffic only provided a limited window of time for the flight to take place. The CAA UAS Sector Team had no means to ensure that the operation of the UAS remained within the limitations of the exemption.

Following the accident, the CAA informed the operator that the exemption was withdrawn.

Safety actions

Both the CAA and the operator have sought to learn from this accident and have implemented a number of measures:

Operator's safety action

> The operator conducted their own investigation into the accident which included a detailed review of its processes and procedures. As part of this process, they generated 53 recommendations for improvement and, as of December 2020, all actions had either been completed or were being in the process of implementation.
>
> The operator is continuing its plans to further develop the Airspeeder aircraft but has now discontinued operation and production of the Airspeeder Mk II to allow design and development of a new, larger Mk III platform. They stated that they have recruited additional, experienced staff and implemented a Safety Management System

CAA safety action

> As a result of this investigation the CAA have conducted a review of the OSC audit process and introduced changes to the oversight process. All audits have inbuilt peer review and are conducted by audit teams. A 'Knowledge Base' has been developed to capture best practice and share knowledge and new audit checklists have been developed within the audit software to capture all the current regulatory requirements. Inspectors and Surveyors have taken on a new, qualitative and subjective approach to auditing, removing the quantitative, checklist-based approach that was used before. Analysis of the competence, value and performance of parts of the OSC are emphasised, as opposed to a 'tick box' approach to checking whether paragraphs or sections are included. An onsite audit procedure is also in development to more accurately target time when face to face with an applicant, focusing on elements that cannot be reviewed remotely.
>
> Additional, experienced resource has been recruited to the UAS Sector Team and mechanisms to include other capability within the CAA have been proposed.
>
> A new format of Operational Authorisation template has been introduced in line with the new regulations that came into force on 31 December 2020 with a view to being clearer and simpler, with a tabular, consistent approach.

A total of 15 Safety Recommendation are made as a result of the investigation:

Safety Recommendation 2021-001

It is recommended that Riotplan Proprietary Limited, trading as Alauda Racing, amends its processes to ensure that it designs, builds and tests unmanned and manned aircraft in accordance with appropriate standards to ensure the safety of those who may be affected by their operation.

Safety Recommendation 2021-002

It is recommended that the Civil Aviation Authority update Civil Aviation Publication 722, Unmanned Aircraft System Operations in UK Airspace – Guidance & Policy, to require detailed evaluation of any Unmanned Aircraft Systems that use onboard systems to mitigate risks with Risk Severity Classifications of 'Major', 'Hazardous' or 'Catastrophic'.

Safety Recommendation 2021-003

It is recommended that the Civil Aviation Authority update Civil Aviation Publication 722, Unmanned Aircraft System Operations in UK Airspace – Guidance & Policy, to provide guidance on the planning, completion and documenting of Radio Frequency surveys to reduce the risk of Radio Frequency interference or signal loss when operating Unmanned Aircraft Systems.

Safety Recommendation 2021-004

It is recommended that the Civil Aviation Authority require Unmanned Aircraft System operators, that use unmanned aircraft which rely on a radio link to operate safety systems, to provide Radio Frequency survey reports to the Civil Aviation Authority for review, to ensure they are suitable and sufficient.

Safety Recommendation 2021-005

It is recommended that the Civil Aviation Authority update Civil Aviation Publication 722, Unmanned Aircraft System Operations in UK Airspace – Guidance & Policy, with guidance on how to define an Unmanned Aircraft System's operational and safety areas, using up-to-date maps, accurate trajectory analysis and human or automated safety system reaction times, to ensure a safe operation.

Safety Recommendation 2021-006

It is recommended that the Civil Aviation Authority update Civil Aviation Publication 722, Unmanned Aircraft System Operations in UK Airspace – Guidance & Policy, to provide examples of Unmanned Aircraft System safety systems.

Safety Recommendation 2021-007

It is recommended that the Civil Aviation Authority introduce requirements to define a minimum standard for safety systems to be installed in Unmanned Aircraft Systems operating under an Operational Authorisation, to ensure adequate mitigation in the event of a malfunction.

Safety Recommendation 2021-008

It is recommended that the Civil Aviation Authority require Unmanned Aircraft System operations under an Operational Authorisation to be fitted with a data recording system which is capable of demonstrating: compliance with the Authorisation's conditions, safe operation and the logging of any failures which may affect the safe operation of the Unmanned Aircraft System.

Safety Recommendation 2021-009

It is recommended that the Civil Aviation Authority specify the minimum requirements for the monitoring of Unmanned Aircraft System high-voltage stored energy devices, to ensure safety of operation.

Safety Recommendation 2021-010

It is recommended that the Civil Aviation Authority specify the minimum requirements for readily identifiable warnings and safety information on Unmanned Aircraft high-voltage stored energy devices to inform 3rd parties of the potential hazard.

Safety Recommendation 2021-011

It is recommended that the Civil Aviation Authority ensure that operators of Unmanned Aircraft Systems have an effective Safety Management System in place prior to issuing an Operational Authorisation.

Safety Recommendation 2021-012

It is recommended that the Civil Aviation Authority, before issuing an Operational Authorisation to operate an Unmanned Aircraft System they have not previously had experience with, carry out a physical examination of the Unmanned Aircraft System to ensure that it is designed and built to suitable standards, and observe a test flight to confirm operation in accordance with the Operating Safety Case.

Safety Recommendation 2021-013

It is recommended that the Civil Aviation Authority update Civil Aviation Publication 722, Unmanned Aircraft System Operations in UK Airspace – Guidance & Policy, to include reference to the consequences of not complying with the conditions of an Operational Authorisation to operate an Unmanned Aircraft System.

Safety Recommendation 2021-014

It is recommended that the Civil Aviation Authority adopt appropriate design, production, maintenance and reliability standards for all Unmanned Aircraft Systems with aircraft capable of imparting over 80 joules of energy.

Safety Recommendation 2021-015

It is recommended that the European Union Aviation Safety Agency adopt appropriate design, production, maintenance and reliability standards for all Unmanned Aircraft Systems with aircraft capable of imparting over 80 joules of energy.

Published: 18 February 2021.

See next page for: **Appendix A – Operator's CAA Exemption**

Appendix A – Operator's CAA Exemption

CIVIL AVIATION AUTHORITY
Air Navigation Order 2016

Exemption – Unmanned Aircraft Systems

1. The Civil Aviation Authority ("CAA"), , in exercise of its powers under Article 266 of the Air Navigation Order 2016 ("the said Order"), as amended, hereby exempts Riotplan Pty Ltd Trading As Alauda Racing ("the operator"), from the provisions of the said Order with the exception of Articles 2-7, 68, 69, 70(1)(b), 75, 76, 86-91, 97-100, 176, 224, 225, 237-242, 247-249, 252, 253, 255-257, 259 and 261-267 thereof, for the purpose of demonstration and trial flights within 50 metres of any person, vessel, vehicle or structure that is not under the control of the operator or chief remote pilot.

2. This exemption is applicable to the following class(es) of unmanned aircraft:

   (a) Multirotor / Helicopter- Listed in schedule I ("the said aircraft")

   at the following location(s) ("the said site(s)"):

   (b) Goodwood Aerodrome (referenced as Map A in accordance with the Operations manual, Volume 1, Version 1.6, Dated 02/07/2019 ("the said operations manual")).

   (c) Goodwood Golf Course (referenced as Map B in accordance with the said operations manual).

3. This Exemption is granted subject to the following conditions, namely, that the unmanned aircraft shall not be flown:

   (a) Unless flights are conducted in accordance with the Alauda Racing Operating Safety Case Volume 1, Version 1.6, dated 02/07/2019 and the associated flight plan as detailed in section 4.5 and the Flight Approval Form, page 41 of the said operations manual;

   (b) Other than by [redacted] ("the Chief Remote Pilot") as designated by the operator;

   (c) Unless there is insurance cover for the small unmanned aircraft that meets the requirements of EC Regulation No. 785/2004;

   (d) Unless the small unmanned aircraft is maintained within the direct, unaided Visual Line of Sight (VLOS) of the chief remote pilot;

   (e) At a horizontal distance exceeding 150 metres from the chief remote pilot;

   (f) At a height exceeding 67 feet above the surface, unless permitted to do so within the flight restriction zone of a protected aerodrome under article 94A (3) of the Order;

   (g) Within the flight restriction zone (see Note 2) of a protected aerodrome, unless in receipt of the appropriate permission as required within article 94A of the Order.

   (h) Over or within a horizontal distance of 150 metres of an organised open-air assembly of more than 1,000 persons;

   (i) Within a distance of 30 metres of any person, vessel, vehicle or structure that is not under the control of the operator or the chief remote pilot, provided that the conditions below are met;

      (i) The operation may only be carried out in accordance with the operating procedures set out in the said operations manual;

      (ii) The horizontal distance between the chief remote pilot and the small unmanned aircraft must not exceed 150 metres.

      (iii) The speed of the unmanned aircraft must not exceed 5 metres per second or a slow walking pace when operating in Map B.

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Appendix A – Operator's CAA Exemption cont

(iv) The speed of the unmanned aircraft must not exceed 11 metres per second when operating in Map A.

(j) Unless it is equipped with a mechanism that will cause the unmanned aircraft to land in the event of disruption to or a failure of any of its control systems, including the radio link, and the chief remote pilot has ensured that such mechanism is in working order before the aircraft commences its flight;

(k) Unless the chief remote pilot is reasonably satisfied that any load carried by the unmanned aircraft is properly secured, that the aircraft is in a safe condition for the specific flight, and that the flight can safely be made taking into account the wind and other significant weather conditions; and

(l) Unless the flights are conducted in accordance with the operating procedures as set out within the said Operations Manual, to include a site safety assessment, as well as records of each flight undertaken. The operator must maintain records of each flight made pursuant to this exemption and must make such records available to the Civil Aviation Authority on request.

4. Any occurrences that take place while the said aircraft is being operated under this Exemption shall be reported in accordance with Regulation (EU) No 376/2014 (the Occurrence Reporting Regulation).

5. All persons under the control of the chief remote pilot of the said aircraft at the operating site and who could be affected by the planned flight operations, must have received a written or oral safety and operational brief on the proposed flight operations and, where necessary, have rehearsed their actions during the planned flight operations.

6. This exemption shall have effect from **3 July 2019 until and including 7 July 2019** unless previously varied, suspended or revoked.

[redacted]

for the Civil Aviation Authority
Date: 3 July 2019
Ref: 20190703 Riotplan Pty Ltd Trading As Alauda Racing Exemption UAS9032 Reduced Distance
SSC Technical Services [redacted]
Distribution:Riotplan Pty Ltd Trading As Alauda Racing [redacted]

SCHEDULE I

Unmanned Aircraft Name:	Alauda Airspeeder	Classification:	Multirotor
Maximum Take-off Mass:	95 Kg	Engine:	4x Brushless DC
Control Frequency:	433 MHz @ 10mW and 900 MHz @ 25mW	Engine Type:	Electric

END OF SCHEDULE I

NOTE 1: UAS operators and chief remote pilots should be aware that the collection of images of identifiable individuals, even inadvertently, when using surveillance cameras mounted on an unmanned surveillance aircraft, may be subject to the General Data Protection Regulation and the Data Protection Act 2018. Further information about these regulations and the circumstances in which they apply can be obtained from the Information Commissioner's Office and website: https://ico.org.uk/for-the-public/drones/

NOTE 2: The "flight restriction zone" of a protected aerodrome can be determined by reference to the table contained within ANO 2016 article 94A, paragraph 7.

NOTE 3: UAS operators and chief remote pilots must be aware of their responsibilities regarding operations from private land and any requirements to obtain the appropriate permission before operating from a particular site. In particular, they must ensure that they observe the relevant trespass laws and do not unwittingly commit a trespass whilst conducting a flight.

NOTE 4: It is the responsibility of the operator to ensure that the radio spectrum used for the command and control link and for any payload communications complies with the relevant Ofcom requirements and that any licenses required for its operation have been obtained. It is also the responsibility of the operator to ensure that the appropriate aircraft radio licence has been obtained for any transmitting radio equipment that is installed or carried on the aircraft, or that is used in connection with the conduct of the flight and that operates in an aeronautical band.

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ACCIDENT

Aircraft Type and Registration:	DJI Matrice 200 V1, (UAS, registration n/a)
No & Type of Engines:	4 electric motors
Year of Manufacture:	2018 (Serial no: 0FZDF7U0P30222)
Date & Time (UTC):	1) 21 September 2019 at 1318 hrs 2) 29 November 2019 at 1022 hrs
Location:	1) Near Raigmore Hospital, Inverness 2) Montrose, Angus
Type of Flight:	Commercial operation
Persons on Board:	Crew - N/A Passengers - N/A
Injuries:	Crew - N/A Passengers - N/A
Nature of Damage:	1) Landing gear, lower cowl, rear antennas and forward camera damaged 2) Landing gear and rear control link antenna damaged
Commander's Licence:	Other
Commander's Age:	39 years
Commander's Flying Experience:	1) 86 hours (of which 27 were on type) Last 90 days - 9 hours Last 28 days - 4 hours 2) 88 hours (of which 29 were on type) Last 90 days - 11 hours Last 28 days - 2 hours
Information Source:	AAIB Field Investigation

Synopsis

The DJI Matrice 200 Unmanned Aircraft System (UAS) was being operated on an automated flight plan to conduct an aerial survey. On the fifth flight of the day, while the aircraft was at a height of 100 m, the ballistic parachute recovery system fitted to the aircraft activated. The aircraft descended under the parachute and was subsequently found on the roof of a nearby house.

Two months later, after having been repaired and fitted with a new parachute system, the aircraft experienced a second parachute deployment. On that occasion the aircraft was being manually flown in GPS mode at a height of 92 m over an area of open ground.

The first accident most likely occurred due to excessive vibration as a result of the parachute system not being securely attached to the airframe.

The investigation was unable to establish the cause of the second accident. There were several warnings in the recorded aircraft's flight log, but analysis of this data did not provide any insight into why the flight was abruptly terminated. However, the parachute

manufacturer considered that the second event involved a valid activation of the parachute system in response to a total aircraft power failure.

The investigation was limited by the availability of recorded flight data for the first accident and a lack of information from the UAS manufacturer. It was therefore unable to establish if there were any common factors between the two accidents, which involved the same aircraft but different parachute units. One Safety Recommendation is made regarding technical support to accident investigations by the UAS manufacturer.

In response to the first accident, the parachute manufacturer and the operator amended their respective procedures for securely attaching the parachute system to the aircraft.

The operator also identified that further emphasis on wind speed and direction was required prior to launch, to provide greater understanding of the drift potential in the case of a parachute deployment.

History of the flight

21 September 2019

The DJI Matrice 200 is a quadcopter UAS with a maximum takeoff mass of 6.14 kg. It is controlled on the ground using a handheld flight controller via radio frequency and a software application (app) running on a tablet device attached to the controller. For the accident flight the takeoff mass was 5.5 kg, which included an underslung camera, two TB55 batteries and a ballistic parachute recovery system.

The UAS was being operated on an automated flight plan using the DJI Go 4 app, to conduct an aerial survey of a helicopter landing site in an urban area. Four flights were completed in the morning without incident. The pilot and observer returned to the same launch point in the afternoon to conduct further flights. The accident occurred on the first flight of the afternoon.

The aircraft was prepared for flight in accordance with the operator's company procedures and all systems indicated normal. Following a normal takeoff, the aircraft climbed to the pre-programmed survey height of 100 m before automatically following the planned route towards the survey site. Soon after, when the aircraft was approximately 250 m from the launch point, the ballistic parachute recovery deployed. The aircraft motors stopped and the aircraft began to descend under the parachute, drifting in the prevailing light winds. The pilot and observer lost sight of the aircraft as it descended behind a tree line. It was subsequently found on the roof of a nearby house and had suffered substantial damage. The recorded flight time was one minute and six seconds. The pilot inspected the aircraft and determined that the thumbscrews on the parachute mounting bracket were tight.

The aircraft was sent to the UAS manufacturer for repair. The parachute system was sent to the parachute manufacturer for examination and analysis of the on-board recorded data from the parachute system, aircraft controller and aircraft flight log[1].

29 November 2019

Following the aircraft's return from repair of the damage incurred in the accident on 21 September 2019, the pilot carried out several test flights without the parachute system installed, over two days totalling two hours flight time. No anomalies were noted. On 29 November 2019, the pilot planned a further test flight prior to conducting an aerial survey, this time with a parachute system installed. This was a new parachute unit from stock and not the same unit that had been fitted on the previous accident flight.

The aircraft and parachute system were prepared for the test flight in accordance with the operator's company procedures and all systems indicated normal. The aircraft was to be manually flown in GPS mode over an area of open ground. After a normal takeoff, the aircraft reached a height of approximately 20 m[2] and the pilot completed the control checks. The aircraft was then commanded to climb and was flown on a south-westerly heading over the open ground. When the aircraft was at a height of 92 m and had travelled 144 m from the launch point, the pilot brought the aircraft into a hover to check the operation of the onboard camera. At this point, one minute and 15 seconds into the flight, the parachute deployed.

The aircraft descended under the parachute drifting to the east in light winds. It remained in sight during the descent and came to rest approximately 130 m from the launch point in grassy, open ground (Figure 1). One of the batteries dislodged as the aircraft struck the ground.

There were no injuries to people on the ground or damage to other property. The pilot inspected the aircraft and determined that the parachute mounting bracket, mounting legs and associated screws were secure. After recovery the aircraft could still be started and operated with the same battery set that had been installed during the accident flight.

The aircraft was sent to the UAS manufacturer for repair. The parachute system was sent to the parachute manufacturer for examination and analysis of the recorded on-board data from both the parachute system and the aircraft's flight log.

Footnote

1 The operator inadvertently sent the aircraft flight log for a previous flight rather than the accident flight. It was subsequently unable to retrieve the flight log for the accident flight.
2 Height above ground displayed on the UAS controller and derived from UAS GPS and Barometric systems

Figure 1
Aircraft after parachute deployment on 29 November 2019

Parachute system information

The operator had fitted a ParaZero SafeAir M200 ballistic parachute recovery system to the aircraft. The SafeAir is an optional after-market safety device that aims to reduce the risk of operating unmanned aircraft over populated areas, by reducing impact energy in the event of an in-flight failure. The M200 model is specifically tailored for use with the DJI Matrice 200 series of unmanned aircraft.

The parachute and the system's internal electronics are mounted on a plate which is fitted on top of the aircraft (Figure 2). A flight termination device, known as TerminateAir, is mounted above the aircraft's battery compartment. A cable connects it to the rest of the parachute system.

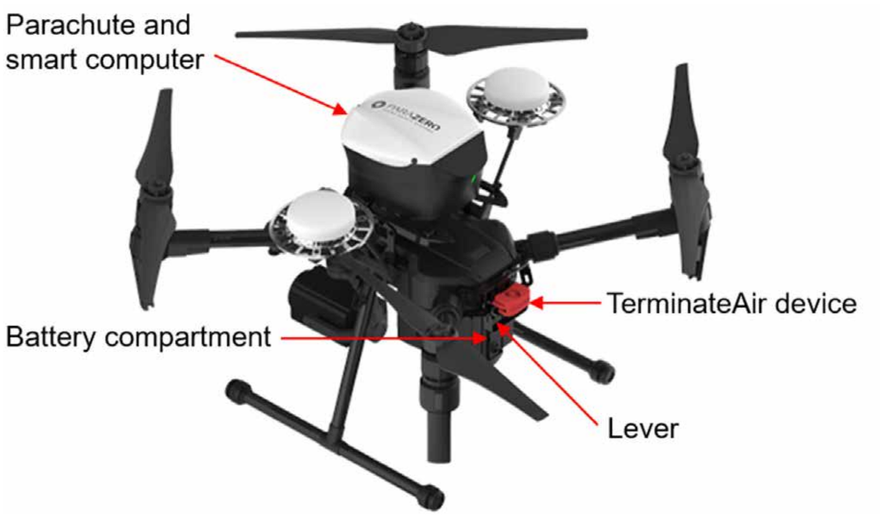

Figure 2
Parazero SafeAir M200 installed on a DJI Matrice 210 RTK unmanned aircraft
(Used with permission of ParaZero Ltd.)

To allow rapid installation and removal of the parachute, the integral mounting plate attaches to two parachute mounting legs via four thumb screws, one in each corner of the mounting plate. The parachute mounting legs are fitted to the aircraft's landing leg joints by removing the existing three landing leg attachment screws and replacing them with three longer screws (Figure 3). A spring washer and plain washer are also installed at each mounting screw. The parachute mounting legs can remain attached to the aircraft between flights.

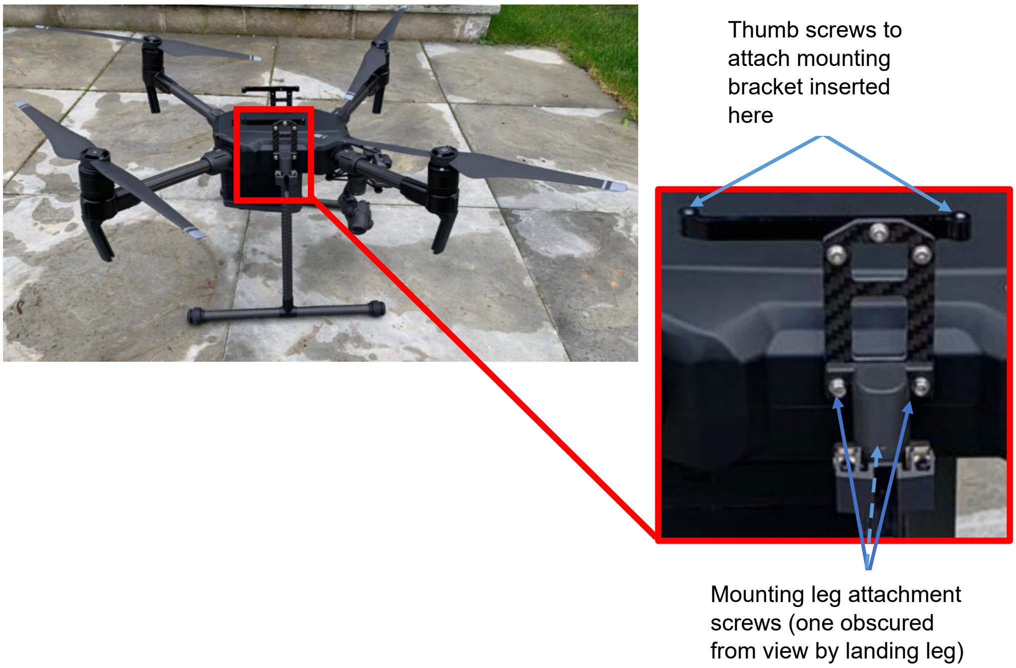

Figure 3

DJI Matrice 210 with mounting legs for SafeAir M200 parachute system attached

The SafeAir system uses independent sensors to monitor the flight parameters of the aircraft. If it detects a critical aircraft failure, the first step of the activation sequence is that the TerminateAir device disconnects the aircraft's batteries, cutting power to the motors. This prevents the motors becoming entangled in the parachute chords or causing laceration injuries. A lever on the TerminateAir is placed across the door of the aircraft's battery compartment, to prevent the batteries being physically ejected.

Having cut power to the motors, the parachute is then activated by a pyrotechnic charge, allowing the aircraft to descend in a controlled manner. An audio alarm alerts bystanders to the potential threat of the descending aircraft.

The SafeAir system will trigger a parachute deployment if it detects an aircraft freefall event. For such an event to be detected, the overall acceleration of the aircraft must drop below 3 m/sec^2 and remain below this threshold for a continuous period of 300 milliseconds (ms). (Note that the aircraft is always subject to the earth's gravity of 1g which would be detected as 9.81 m/sec^2 during hovering flight.) The 300 ms delay was designed to mitigate the differences between the acceleration measured by the SafeAir and the aircraft. For example, this overall acceleration is resolved from the X, Y and Z accelerations that are measured within the SafeAir unit itself, and no adjustments are made to these values to transform them to where the accelerations are measured on the aircraft. Vibration levels may also be different at the two measurement locations.

Recorded data analysis, examination and testing parachute manufacturer

21 September 2019 flight

The parachute manufacturer analysed the log file from the parachute system. This showed an extensive vibration pattern after 9000 on the 'Time stamp' x-axis (Figure 4), which subsequently triggered the parachute deployment. The vibration pattern changed after deployment of the parachute as the power to the aircraft motors was cut by the TerminateAir system.

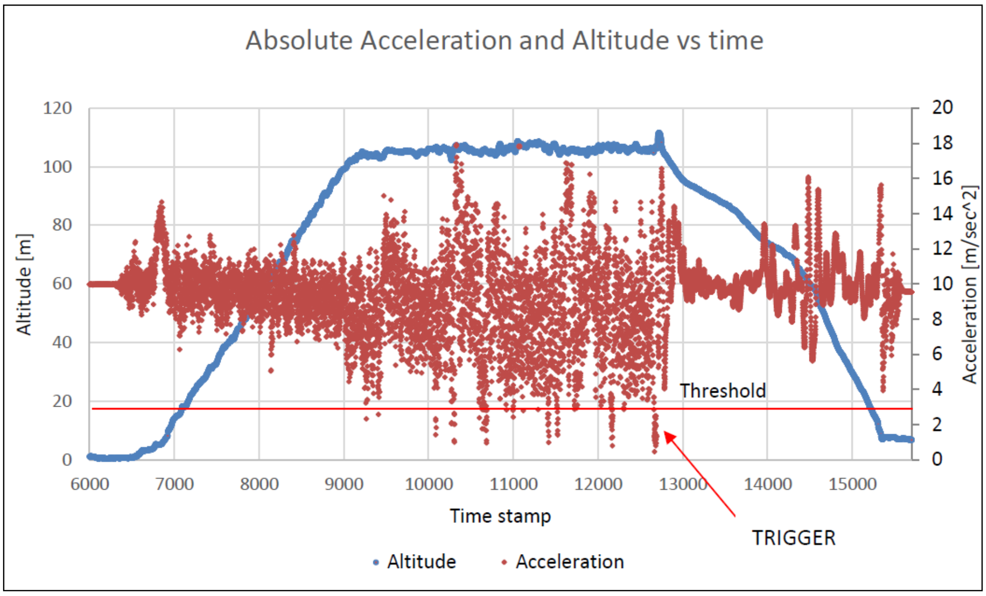

Figure 4

Plot showing salient recorded data from SafeAir for the accident flight

Laboratory testing by the manufacturer of the parachute system did not reveal any electrical or mechanical anomalies. The system was serviced to allow it to be installed on a DJI Matrice 200 for flight testing. The flight computer elements were not modified and a dummy pyrotechnic device was installed. The first test flight produced a stable flight log and did not result in a parachute deployment trigger, despite a flight pattern involving rapid changes in altitude and acceleration.

The parachute manufacturer advised that vibration can arise due to an attachment problem between the SafeAir system and the UAS. To try and replicate the unusual vibration pattern seen during the accident flight, a second test flight was performed. For this flight, the four thumb screws which connect the parachute to its mounting legs, were intentionally loosened. This produced an extensive vibration pattern which triggered a parachute deployment signal (Figure 5). Unlike the accident flight, the vibration pattern continued after the parachute trigger, as the dummy pyrotechnic device prevented the parachute from deploying.

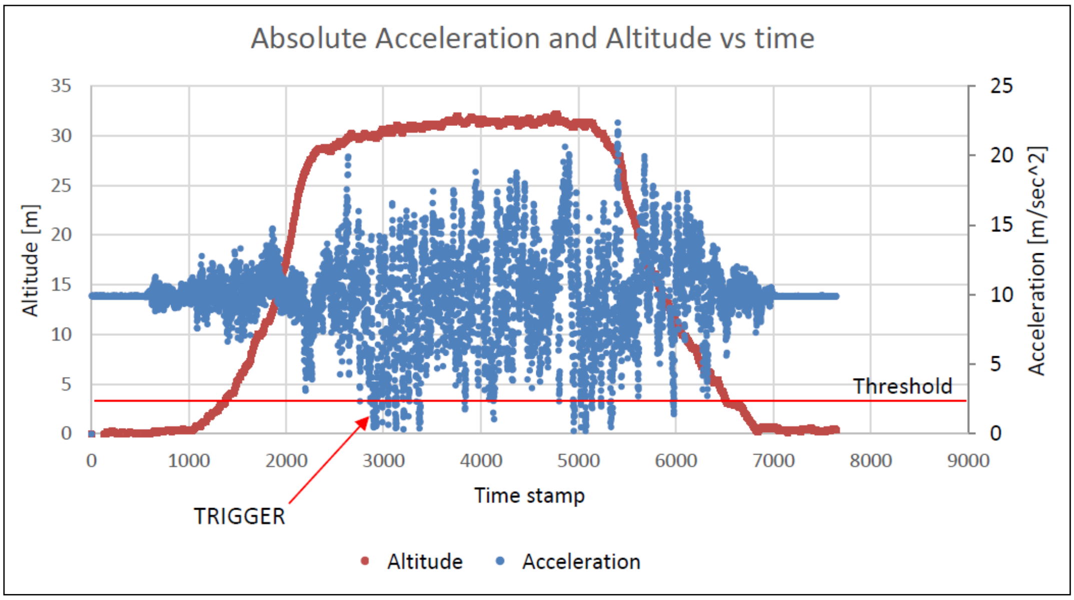

Figure 5

Plot showing salient recorded data from SafeAir for the second test flight

The parachute manufacturer concluded that it was highly probably that the cause of the parachute deployment on the 21 September 2019 accident flight was induced vibration due to loose attachment of the SafeAir unit to the aircraft.

29 November 2019 flight

The parachute manufacturer analysed the log files from the parachute system and the aircraft and stated that both files were similar, with identical altitude and acceleration, until the point of parachute deployment. The aircraft's data log ended at cruise altitude, while the parachute system log (Figure 6) continued to record a fall in altitude, followed by the parachute deployment, which was characterised by erratic altitude and acceleration readings, before a constant rate descent to the ground.

The parachute manufacturer noted several warnings/errors in the aircraft's flight log and it considered that the sudden end of the aircraft's data log could be explained by a total aircraft power failure. It therefore did not examine the SafeAir system and no test flights were performed.

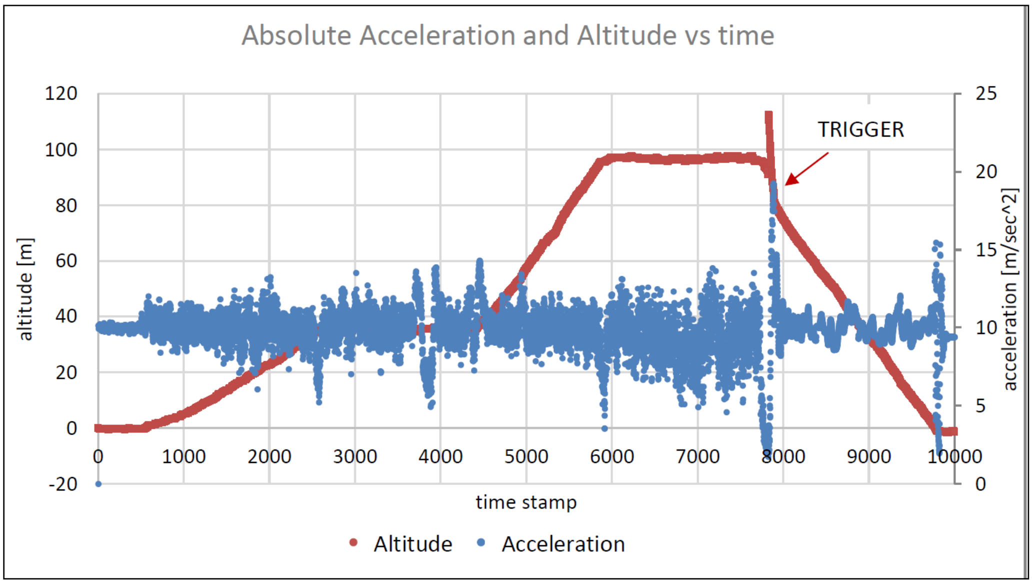

Figure 6

Plot showing salient recorded data from SafeAir for the second parachute deployment

AAIB review of aircraft on-board recorded data

A review of the aircraft system's logged data for both flights was made by the AAIB and comparisons were made with SafeAir logged data provided by the parachute system manufacturer. As detailed in AAIB report AAIB-26256, published in Bulletin 2/2021, alignment of the aircraft and parachute system data was difficult to establish and hindered the investigation's ability to identify the reason for the parachute deployments. Specifically, for the 21 September 2019 flight, as no copy of the aircraft's flight log was available to analyse, the only data available was that recorded in the aircraft controller log file. This log file only records basic flight parameters and does not record any that are common with the parachute system log that could be of use, such as accelerations, to accurately correlate both sets of data. However, it does record status messages of the system including warnings.

21 September 2019 flight

The recorded aircraft data confirmed that the recording ended abruptly after about 65 seconds of flight with the aircraft in the hover about 100 m above the ground, and at which point the energy level (state of charge (SOC)) of the aircraft's batteries was 96% (Figure 7). Not shown in Figure 7 is the aircraft's vertical velocity which changes from zero (whilst the aircraft is hovering) to 0.4 m/s in a downward direction over the last 0.2 s of recording. No warnings were recorded in the aircraft's controller log file.

The acceleration recorded by the parachute system is also plotted in Figure 7 and shows that the amplitude of the oscillations in acceleration appear in places to be biased below 9.81 m/sec^2 (1g) and dropping briefly below the 3 m/sec^2 trigger threshold about 20 times.

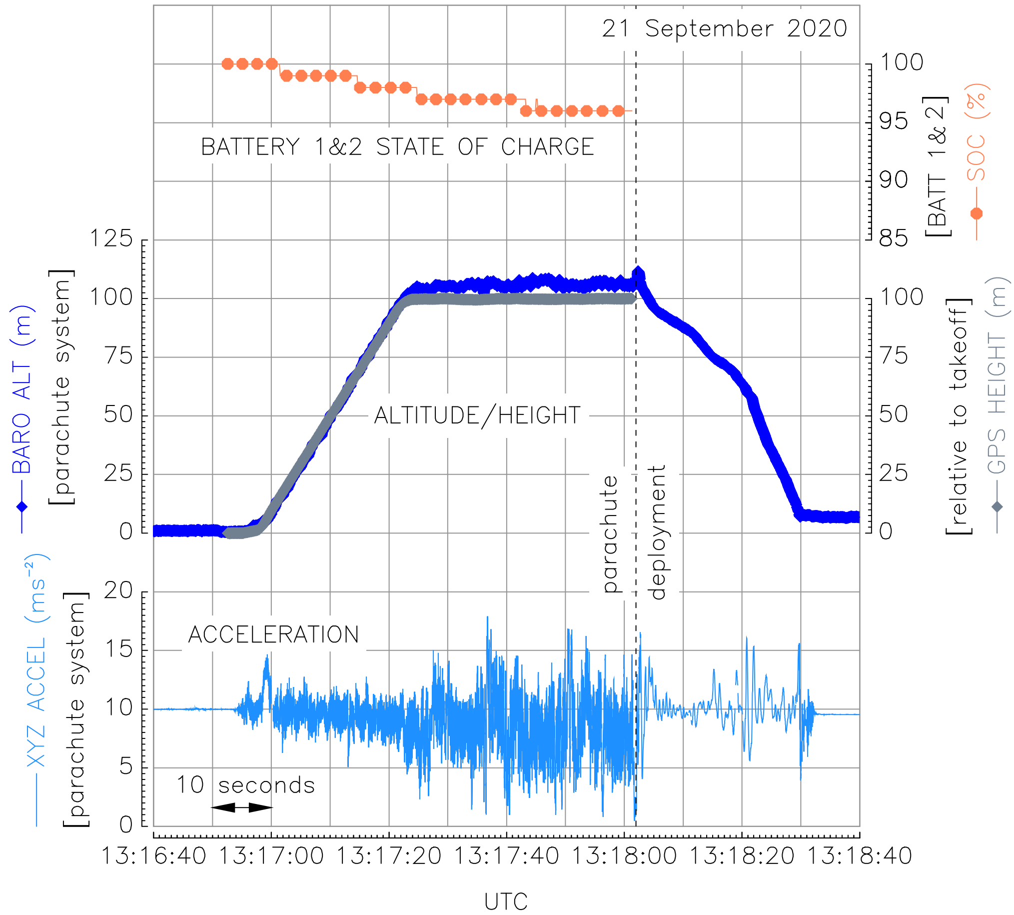

Figure 7

Flight data from the aircraft's controller and the parachute system for the 21 September 2019 accident flight

29 November 2019 flight

The recorded aircraft data confirmed that the recording ended abruptly after about 75 seconds of flight with the aircraft in the hover about 93 m above the ground, and at which point the energy level (state of charge(SOC)) of the aircraft's batteries was 94% (Figure 8).

Figure 8 also shows some of the warnings recorded in the aircraft controller log[3]. These included seven 'Propeller Fell Off' warnings, prior to takeoff, three of which also contained the message 'Drone is Vibrating. Not Enough Force/ESC Error.' After takeoff there were another 15 'Propeller Fell Off' warnings, 12 of which contained the message 'Drone is Vibrating. Not Enough Force/ESC Error'. Some of these also contained the message 'Barometer is Dead in Air. Motor is Blocked'.

Footnote

3 There were also one 'Low battery temperature', six 'Low Satellites Error' and one 'Compass Error' warnings.

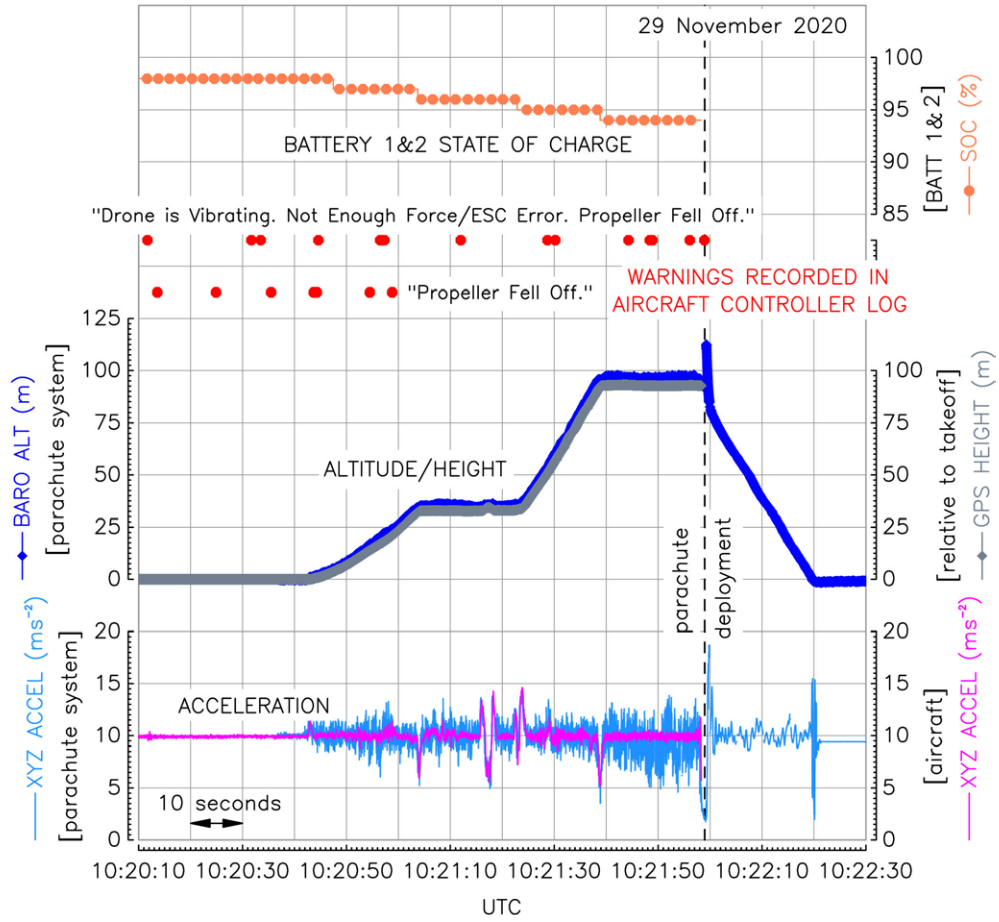

Figure 8

Flight data from the aircraft and controller and the parachute system for the 29 November 2019 accident flight

Figure 8 also compares the aircraft's altitude and acceleration data with the equivalent data from the SafeAir log file. It shows that as the flight progressed, the acceleration recorded by the SafeAir system grew in amplitude compared to that recorded by the aircraft. The two data sets were aligned to within 10 ms at the start and throughout most of the recording, by matching the acceleration peaks and troughs associated with level changes in altitude. The accelerations throughout the flight were generally smaller in amplitude than those of the 21 September 2019 accident flight shown in Figure 7 and did not suggest the presence of excessive vibration

Figure 9 is a close up of the end of the aircraft data and when the parachute was deployed. The aircraft data shows that all four motors started to slow down over the last 0.1 s of recording with a corresponding decrease in the height and acceleration. The drop in the aircraft's acceleration is similar to that recorded by the parachute system; however, they are misaligned by about 150 ms. The parachute system's acceleration continued the fall below the parachute trigger threshold where it remained for 300 ms before triggering the TerminateAir and then deploying the parachute 50 ms later.

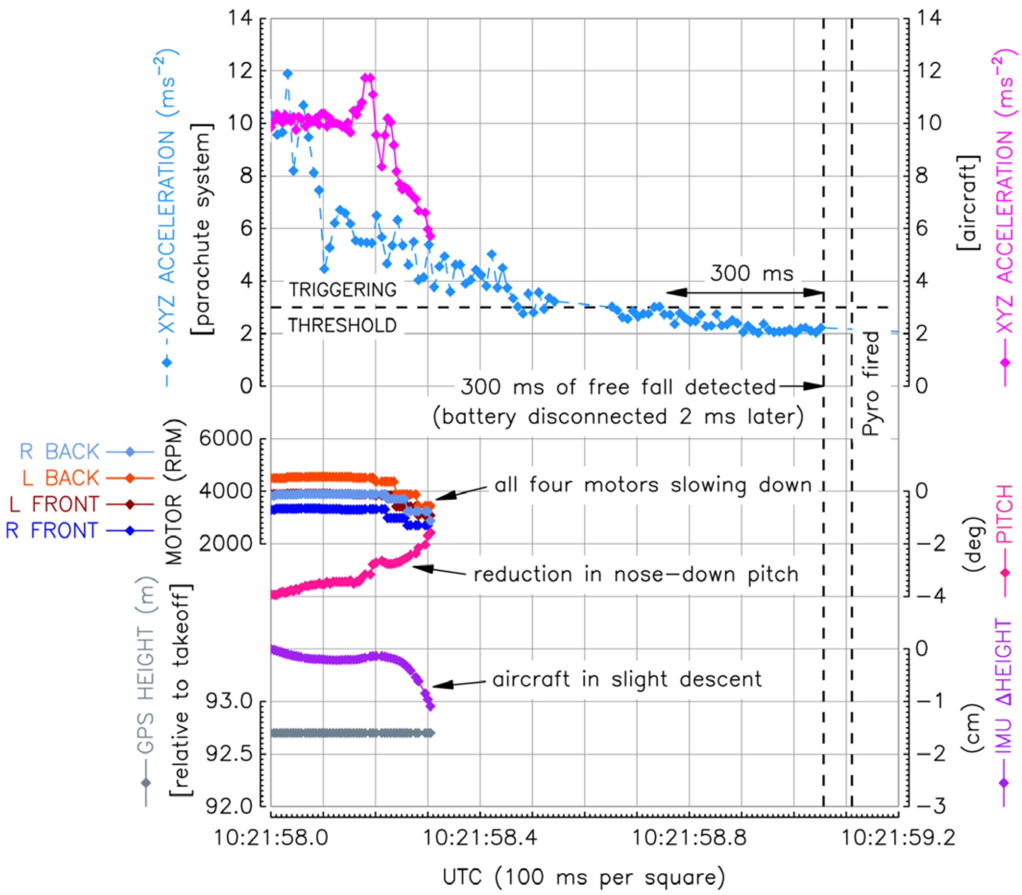

Figure 9

Comparison of acceleration prior to parachute deployment

Information from the operator

The operator used the SafeAir fitted to the DJI Matrice 200 as an additional safety mitigation when conducting aerial surveys in densely populated areas. It has extended visual line of sight (EVLOS) permissions to allow it to conduct such operations.

Prior to the 21 September 2019 flight, approximately 11 hours of flight time had been accumulated without incident on the aircraft with the SafeAir fitted, over the preceding year. This included a mix of manually flown and autonomous flights conducted at different weights.

The pilot reported that prior to the 21 September 2019 flight, the aircraft had been prepared for flight in accordance with its pre-flight procedures, which included a check that the thumbscrews for the parachute system were tight. When the aircraft was recovered following the accident, the SafeAir unit appeared securely attached and the thumbscrews were tight. The security of the parachute mounting structure was not checked before or after the flight, as there was no specific requirement to do so.

When the aircraft was returned to the operator in November 2019, following repair by the aircraft manufacturer, the operator inspected the SafeAir mounting legs and noted that the attachment screws were loose and had not been installed in accordance with the SafeAir installation guide. Spring washers were missing from four of the screws and flat washers were missing from the other two screws. It was highly likely the mounting legs had been removed during the repair at the aircraft manufacturer's facility and so the post-repair condition of mounting leg attachment screws and washers did not provide an indication of their pre-accident condition.

The operator subsequently removed and replaced all the SafeAir mounting leg attachment screws and washers and added a thread-locking compound to the screw threads. It amended its pre-flight procedures to check the security of mounting leg screws and correct fitment of washers. It also updated its maintenance procedures to document when the SafeAir mounting legs were fitted and removed. These actions were taken prior to the 29 November 2019 flight.

Information from the parachute manufacturer

21 September 2019 flight

The parachute manufacturer stated that the effectiveness of all attachment screws had been demonstrated during the several hundreds of flight hours accumulated by the SafeAir M-200. It indicated that screws that were not properly tightened could become looser during flight due to aircraft's vibrations. The SafeAir M200 installation guide included a pre-flight requirement to check the thumb screws were 'firmly closed'.

The parachute manufacturer did not specifically flight test the system with loose mounting leg attachment screws, but it considered this would create a similar vibration pattern to that demonstrated by loose thumb screws. It did not consider it necessary to introduce a torque requirement for the mounting leg attachment screws, indicating that a pre-flight check to make sure the screws were secure would be sufficient. Accordingly, it amended the pre-flight check in the installation guide to also check the security of the mounting leg attachment screws.

Information from the UAS manufacturer

The UAS manufacturer advised that it is sometimes necessary to remove hardware associated with parachute systems when aircraft are repaired or serviced. It stated that its repair staff are not qualified on such external elements and cannot therefore guarantee the airworthiness of such external systems after repair. The UAS manufacturer recommends additional service by certified personnel if they have been worked on/removed by repair staff.

Despite several requests the UAS manufacturer did not provide any other data relevant to the parachute deployment events.

Analysis

21 September 2019 flight

Following the first accident on 21 September 2019, a review of the parachute system on-board recorded data identified the presence of a strong vibration pattern. A test flight conducted with intentionally loosened mounting bracket thumb screws produced a similar vibration pattern to that seen during the accident flight.

The operator indicated that the thumbscrews had been correctly tightened when the parachute was fitted prior to the flight and were confirmed to be tight when the parachute system was removed after the accident. The parachute mounting legs and attachment screws were not specifically checked, but these screws were subsequently found to be loose with incorrect washer configurations when the aircraft was returned after repair. It is likely that the mounting legs were removed and improperly reassembled during the repair, so nothing could be deduced about the pre-accident condition of the attachment screws. However, the parachute manufacturer advised that the expected vibration pattern arising from loose mounting leg attachment screws would be similar to that arising from loose thumb screws. The parachute mounting legs had not been disturbed between the four uneventful morning flights and the accident flight, but had they been slightly loose to start, they could have become progressively more so during the flights, due to normal aircraft vibrations.

The AAIB independently reviewed both the recorded data from the aircraft controller and parachute system. The limited aircraft flight data meant that the investigation was unable to determine the aircraft's performance and attitude when its recording stopped, and how this compared with data from the parachute system data. The accelerations recorded from the parachute system were, however, large in amplitude compared to what would normally be experienced and recorded by the aircraft. As discussed in AAIB report AAIB-26256, the accelerations are measured in different places by the two systems and so differences are expected which the 300 ms trigger delay tries to mitigate against to avoid false positive detections. No warnings were issued by the aircraft and the battery energy levels were above 95% so there is no evidence to suggest the aircraft was experiencing a problem; however, access to the aircraft's flight log would have allowed a more complete assessment.

29 November 2019

The AAIB independently reviewed both the recorded data from the aircraft and parachute system. There were numerous warnings issued by the aircraft stating that the aircraft was vibrating and that a propeller had fallen off before and after takeoff. These warnings were inconsistent with the acceleration data recorded by the aircraft and the fact that the aircraft was able to get airborne and were therefore considered spurious. The flight did not exhibit the same vibration pattern as the first accident. The drop in motor rpm, acceleration and height during the last 0.1 s of recording could be an indication of the aircraft losing power; however, no related warnings were issued to indicate there was a problem. The batteries had 94% SOC remaining when the flight ended. Additionally, following the accident the aircraft was started and operated using the same battery set; this appears inconsistent with a total power loss.

Without additional information from the UAS manufacturer, particularly about the meaning and validity of the warnings, it was not possible to establish the reason for the sudden termination of the flight or whether there were any common causal factors between both accidents. An absence of information from the UAS manufacturer also impeded identification of a definitive cause during the investigation of a ballistic parachute deployment to a DJI Matrice 210, which is reported in AAIB report AAIB-26256, published in AAIB Bulletin 2/2021.

Support to accident investigations

For accident investigations to be effective, access to relevant technical information from aircraft manufacturers is often essential to assist investigators in understanding the causes of the accident and identifying areas which would benefit from safety improvement.

The AAIB has actively investigated UAS accidents since 2015 and has experienced varying degrees of support from UAS manufacturers. Several of those investigations have involved the UAS manufacturer referenced in this report. AAIB Report EW/G2018/09/04, published in AAIB Bulletin 11/2019 involving an accident to a DJI Matrice 210, provides an example of effective engagement with this UAS manufacturer which enabled the investigation to fully understand the aircraft battery issues being investigated. The report documents the safety actions taken by the manufacturer to develop and roll out firmware changes for the battery and aircraft.

Increasingly the UAS accidents investigated by the AAIB involve those engaged in commercial operations, which is reflective of the rapid growth of such operations in the UK. Until 31 December 2020, UAS operators carrying out commercial operations in the UK required a Permission for Commercial Operations (PfCO) issued by the Civil Aviation Authority (CAA), of which at the time of writing 6,074 had been issued[4]. The rapid growth in UAS commercial operations is not unique to the UK, and safety investigation authorities in other States are also beginning to investigate UAS accidents. Despite their use in commercial operations, it is acknowledged that many small UAS fall into the category of consumer electronics, which are not required to be certified and have product life cycles much shorter than those of manned aircraft. Therefore, it is recognised that UAS manufacturers may not be structured or resourced to provide detailed technical support to investigations. Nonetheless, when engagement with an aircraft manufacturer is not effective, the ability to learn from accidents may be compromised and the opportunity to improve flight safety lost. Therefore, the following Safety Recommendation is made:

Safety Recommendation 2020-016

It is recommended that DJI introduce an effective system for providing timely technical support to State safety investigations.

Footnote

[4] 20201204RptUAVcurrent.pdf (caa.co.uk) accessed 7 December 2020. On 31 December 2020 new UAS regulations come into force in the UK which describe the new authorisations required for various categories of UAS operation.

Conclusion

Two separate routine flights of an unmanned aircraft terminated prematurely when the ballistic parachute recovery system activated. The first accident most likely occurred due to excessive vibration as a result of the parachute system not being securely attached to the airframe. The investigation was unable to establish the cause of the second accident.

The investigation was limited by the availability of recorded flight data for the first accident. Without additional information from the UAS manufacturer it was not possible to establish if there were any common factors between the two accidents.

Safety actions

In response to the first accident, the parachute manufacturer amended the pre-flight checks in the SafeAir M200 installation guide to check the security of the mounting leg attachment screws.

In response to the first accident the operator:

- added a thread-locking compound to the screw threads of the parachute mounting leg attachment screws.
- amended its pre-flight procedures to check the security of mounting leg screws and correct fitment of washers.
- updated its maintenance procedures to document when the parachute mounting legs were fitted to and removed from the aircraft.
- identified that further emphasis on wind speed and direction was required prior to launch, to provide greater understanding of the drift potential in the case of a parachute deployment.

Published: 18 February 2021.

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:	Piaggio P 180 Avanti II, D-IPPY
No & Type of Engines:	2 Pratt & Whitney Canada PT6A–66B turboprop engines
Year of Manufacture:	2018 (Serial no: 3010)
Date & Time (UTC):	19 September 2020 at 0755 hrs
Location:	Near Southend-on-Sea, Essex
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 2 Passengers - 3
Injuries:	Crew - None Passengers - None
Nature of Damage:	None
Commander's Licence:	Commercial Pilot's Licence
Commander's Age:	42 years
Commander's Flying Experience:	4,400 hours (of which 1,600 were on type) Last 90 days - 180 hours Last 28 days - 60 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot and additional enquiries by the AAIB

The aircraft departed London Luton Airport en route to Riviera Airport, Albenga, Italy, without event. During the climb passing FL220, the commander, who was PF, heard a dull sound that he believed was an outflow valve opening in the rear of the aircraft. Upon observing the cabin altitude, it indicated a climb of about 4,000 ft/min. The PM informed ATC that they were going to level off at FL230 in order to monitor the cabin altitude. As the cabin altitude continued to climb, and was approaching 10,000 ft, the commander manually deployed the passenger's oxygen masks and the crew donned theirs.

A PAN was declared and an emergency descent to FL100 requested to ATC. The aircraft was initially cleared to FL200, due to traffic below, but was soon re-cleared to FL100. The descent was continued and the appropriate checklist completed. The aircraft diverted to London Biggin Hill Airport where it landed, with the RFFS in attendance, without further event. There were no injuries.

The engineering investigation discovered a clamp connecting a hose to the Environmental Control System had become lose, possibly as a result of vibration, leading to a loss of cabin pressure. After rectification the aircraft was released to service.

ACCIDENT

Aircraft Type and Registration:	Cessna F150K, G-BJOV
No & Type of Engines:	1 Continental Motors Corp O-200-A piston engine
Year of Manufacture:	1970 (Serial no: 558)
Date & Time (UTC):	1 October 2020 at 1615 hrs
Location:	Near Tiffenden Airfield, Kent
Type of Flight:	Private
Persons on Board:	Crew - 2 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Severe damage to nose landing gear. Damage to wings, fuselage, engine and propeller
Commander's Licence:	Private Pilot's Licence
Commander's Age:	55 years
Commander's Flying Experience:	1,146 hours (of which 851 were on type) Last 90 days - 28 hours Last 28 days - 6 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

Synopsis

Likely resulting from the combination of a tailwind and an unintentionally steep approach, the aircraft experienced a heavy landing further along the runway than planned. The heavy landing was followed by a high bounce during which the PIC took control and initiated a go-around. Despite the application of full power and a reduction of flap angle to reduce drag, the aircraft struggled to climb above successive tree lines beyond the airfield boundary. When it became apparent that the aircraft would not clear them, the PIC was forced to carry out an emergency landing in a field just short of a third line of trees. The nose gear collapsed after touchdown and the aircraft slid to a halt. Both pilots were able to exit the aircraft unaided and uninjured. The PIC reflected that discontinuing the initial steep approach and going around before touchdown would have been a better option in the circumstances.

History of the flight

The aircraft was flown from Headcorn Aerodrome to Tiffenden Airfield by two pilots qualified on type. The PIC was in the right seat as non-handling pilot. To take advantage of the uphill slope to reduce the landing roll, G-BJOV was positioned to land on Runway 07 despite a 5 kt tailwind. The PIC reported that it was his normal practice to accept a light tailwind on Runway 07. This was because, when landing into a light headwind on Runway 25, the presence of trees in the undershoot combined with the downhill slope would result in an estimated 200 m longer landing distance than for Runway 07. On final, the handling pilot judged that he was high and selected full flap (40°) to increase the descent rate.

Likely because of the steep approach coupled with the tailwind, the aircraft landed heavily further along the runway than planned, approximately abeam the windsock (Figure 1). Due to the heavy landing G-BJOV bounced back into the air. With less than half the runway remaining ahead, the PIC took control and initiated a go-around.

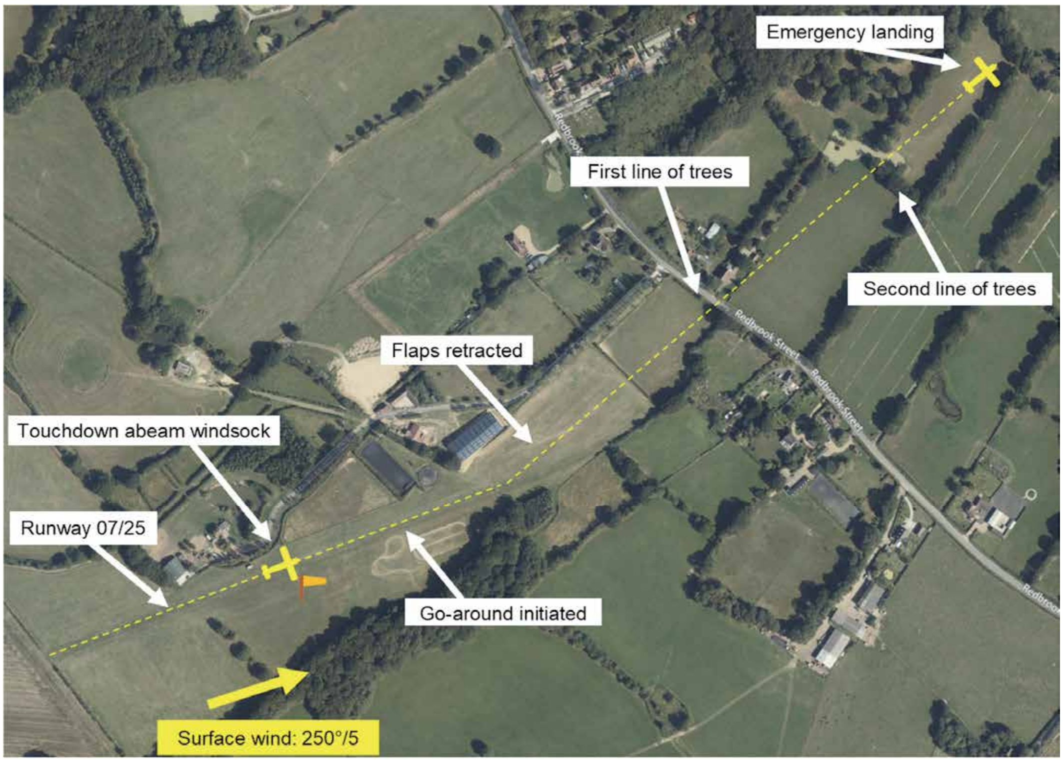

Figure 1

Overview of accident ground track
(image courtesy of Ordnance Survey ©2021 TomTom)

The aircraft was not climbing as expected so the PIC asked the second pilot to help by raising the flaps in stages to reduce drag. The PIC then lowered the nose to gain speed but needed to raise it again to clear trees at the airfield boundary. As he did so the stall warner sounded.

Once clear of the boundary trees, the PIC again attempted to accelerate by lowering the nose. While this helped, a further line of trees approximately 100 m beyond the first meant that the pilot had to raise the nose once more. The stall warner sounded again and both pilots felt the landing gear striking branches as they passed the treetops.

The PIC again lowered the nose to accelerate, but as he raised it to clear the next set of trees a wing drop to the left developed. He was able to counter this by lowering the nose and using opposite rudder, but it became apparent that they would not be able to climb over the treeline ahead. The PIC felt he had no option but to carry out an immediate emergency landing in the field. At touchdown, the nosewheel collapsed and the aircraft slid to a halt at the edge of the field (Figure 2).

Both pilots were able to evacuate the aircraft without assistance and were unhurt in the accident. The PIC reflected that discontinuing the initial steep approach and going-around before touchdown would have been a better option in the circumstances.

Figure 2

G-BJOV in the treeline
(image courtesy of PIC)

Airfield information

Tiffenden is a private unlicensed grass airfield. It has two marked strips, Runway 06/24 and Runway 07/25, which is the longer; Runway 06/24 is rarely used. Both runways slope down towards the west. To avoid buildings beyond the end of the runway, the go-around track from Runway 07 requires a left turn to parallel Runway 06. The Pooley's guide warns pilots that '*rising ground and trees*' beyond the end of Runway 07 pose a hazard for go-arounds.

Discussion

It is likely that the heavy landing and bounce resulted from continuing with a steep approach rather than pre-emptively going around. The upsloping runway would have added to the challenge of judging when and how much to flare the aircraft before touchdown.

As highlighted in the Pooley's guide, an easterly go-around at Tiffenden is complicated by rising ground and trees. As well as contributing to the landing being further along the runway than expected, the tailwind would have increased the aircraft's groundspeed, thus reducing the time available to accelerate and climb above these trees during the early stages of the go-around.

The heavy bounce would have reduced the aircraft's speed, making an already challenging go-around significantly more difficult from a lower energy state. Despite the application of full power, there was insufficient time to establish a sustainable climb before the PIC needed to raise the aircraft's nose to clear the first treeline. As the aircraft approached the stall, drag would have risen markedly, reducing the aircraft's thrust margin and therefore its ability to accelerate.

Conclusion

Landings further along the runway than expected can result from a variety of causes and are an ever present hazard in aviation. When coupled with a challenging go-around owing to obstacles in the aircraft's path, the margin for error is further reduced and additional mitigation, such as an earlier than normal go-around decision point, should be considered. As the PIC reflected, had the steep approach and/or the touchdown being further along the runway than expected triggered a proactive go-around before landing, a successful outcome would have been more likely.

ACCIDENT

Aircraft Type and Registration:	Jabiru J430, G-KIDD
No & Type of Engines:	1 Jabiru 3300A piston engine
Year of Manufacture:	2006 (Serial no: PFA 336-14541)
Date & Time (UTC):	24 March 2020 at 1400 hrs
Location:	High Cross Airfield, Hertfordshire
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Damage to nose leg and landing gear, engine components and cowling, and wing mounts
Commander's Licence:	Private Pilot's Licence
Commander's Age:	53 years
Commander's Flying Experience:	520 hours (of which 80 were on type) Last 90 days – 0 hours Last 28 days – 0 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot and further enquiries by the AAIB

History of the flight

The pilot planned to do a short recency and maintenance check flight. After an uneventful start up and takeoff from grass Runway 23, the aircraft climbed to about 2,000 ft and headed to the west for some general handling. At the time the weather was good with a wind from about 240° at 12 kt.

Whilst in an orbit the engine started to run roughly. The pilot throttled back the engine, checked the indications, selected carburettor heat ON and turned back towards the airstrip. The engine then "spluttered" and stopped; a restart was unsuccessful. Appreciating he was committed to a forced landing, the pilot selected best glide speed and continued towards the airstrip from the south-west. Realising he was too low to make an approach to Runway 23, he elected to land, with a tailwind, on Runway 05. Once over the runway the aircraft floated at about 8 to 10 feet. As the end of the runway was approaching, the pilot decided to pitch the aircraft's nose into the runway to stop the aircraft, during which the nose leg collapsed (Figure 1). The pilot vacated the aircraft uninjured.

Figure 1

G-KIDD after the accident
(Used with permission)

Upon draining the fuel, a significant amount of discoloured water was discovered. The carburettor float was also full of water.

The pilot believed that, given the amount of water, it was present in the fuel he last uplifted six weeks earlier. He had not performed a fuel drain check for water prior to departing; something he would not be omitting again.

SERIOUS INCIDENT

Aircraft Type and Registration:	Piper PA-28-161, G-BJCA
No & Type of Engines:	1 Lycoming O-320-D3G piston engine
Year of Manufacture:	1979 (Serial no: 28-7916473)
Date & Time (UTC):	10 July 2020 at 1320 hrs
Location:	Shoreham Airport, West Sussex
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	None
Commander's Licence:	Private Pilot's Licence
Commander's Age:	62 years
Commander's Flying Experience:	453 hours (of which 134 were on type) Last 90 days - 0 hours Last 28 days - 0 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

Synopsis

Following an approach in crosswind conditions, the aircraft landed nosewheel first and at a faster than normal touchdown speed. Thereafter, the aircraft nose swung left and the aircraft departed the paved runway onto the adjacent grass. The pilot initiated a go-around and returned for a normal approach and landing.

History of the flight

The flight was described by the pilot as a "de-rusting flight" following the easing of public health restrictions, which had prevented him flying for four months. After two hours of general handling in the local area, the aircraft returned to Shoreham Airport with the intention to land on Runway 02. The wind was forecast to be from 330° at 11 kt and the reported wind at the time of the incident was from 300° at 11 kt. The pilot recalled some turbulence associated with thermals on approach.

The aircraft landed further along the runway than normal and to the left of the runway centreline. The nosewheel touched down before the main wheels in what the pilot described as a "poor landing". He reported poor controllability on the ground and after a ground run of six seconds the aircraft nose swung to the left.

The aircraft then departed the asphalt runway onto the adjacent grass surface which the pilot referred to as "recently mown and well maintained". He immediately applied full power and the aircraft became airborne after three seconds. The subsequent approach and landing were uneventful. The aircraft did not sustain any damage.

The pilot stated that with hindsight, he should have "factored in the rust and gone around" off his first approach. He also commented that he could have delayed the 'de-rusting' flight to a day with more favourable wind conditions.

Aircraft performance

In the performance section of the POH, the landing distance graph specifies a touchdown airspeed of 39 kt for the declared landing weight. The pilot did not recall higher than normal speed during the approach. However, analysis of video footage indicates that the aircraft's airspeed was in the region of 64 kt as it crossed the runway threshold.

Nosewheel landing

The FAA *'Airplane Flying Handbook'* (Chapter 8)[1] states:

> *'After touchdown, avoid the tendency to apply forward pressure on the yoke, as this may result in wheel barrowing and possible loss of control.'*

And:

> *'When a pilot permits the airplane weight to become concentrated about the nose wheel during the takeoff or landing roll, a condition known as wheel barrowing occurs. Wheel barrowing may cause loss of directional control during the landing roll because... the airplane tends to swerve or pivot on the nose wheel, particularly in crosswind conditions. One of the most common causes of wheel barrowing during the landing roll is a simultaneous touchdown of the main and nose wheel with excessive speed, followed by application of forward pressure on the elevator control. Usually, the situation can be corrected by smoothly applying back-elevator pressure.'*

It adds:

> *'In nose-wheel airplanes, a ground loop is almost always a result of wheel barrowing. A pilot must be aware that even though the nose-wheel type airplane is less prone than the tailwheel-type airplane, virtually every type of airplane, including large multi-engine airplanes, can be made to ground loop when sufficiently mishandled.'*

Footnote

[1] https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/airplane_handbook/media/10_afh_ch8.pdf [accessed January 2021]

Conclusion

The landing exhibited the characteristics of 'wheel barrowing' as described in the FAA's *'Airplane Flying Handbook'.* It is likely that excess speed on final approach led to nosedown pitch inputs by the pilot and caused the nosewheel to touch down before the main wheels. The additional effect of the crosswind on a directionally unstable aircraft, without a correcting input, led to the runway excursion. The short time the aircraft spent on the grass before becoming airborne indicates that it remained close to flying speed during the rollout.

ACCIDENT

Aircraft Type and Registration:	Reims Cessna F152, G-BHFI
No & Type of Engines:	1 Lycoming O-235-L2C piston engine
Year of Manufacture:	1980 (Serial no: 1685)
Date & Time (UTC):	8 September 2020 at 1610 hrs
Location:	Wards Stone, Forest of Bowland, Lancashire
Type of Flight:	Training
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Damaged windscreen and right main landing gear
Commander's Licence:	Pilot under training
Commander's Age:	42 years
Commander's Flying Experience:	49 hours (of which 48 were on type) Last 90 days - 13 hours Last 28 days - 12 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

Synopsis

A student pilot had been briefed to carry out a planned navigation exercise from Blackpool Airport (EGNH) around the local area before returning to Blackpool. About halfway around the route, the pilot attempted to avoid cloud but inadvertently entered IMC and became disorientated. During his attempts to maintain controlled flight, he briefly contacted the ground, but he was able to climb away and, with the assistance of ATC and another aircraft relaying messages, land back at Blackpool.

A report into the event concluded that it was made more likely by: the inexperience of the student pilot; flying below MSA; the pilot not recognising a general deterioration in the weather conditions; and the pilot expecting the weather to improve because it had done so earlier. The training organisation plans to introduce improved training and pre-flight procedures to reduce the risk of this type of accident occurring in the future.

History of the flight

The student pilot had completed all the technical aspects of his PPL course, including two flights covering the simulated IMC element using 'Foggles'[1], and was building his solo flying hours in preparation for his skills test. The route for the flight was from Blackpool

Footnote

[1] 'Foggles' are spectacles worn by the pilot under training to simulate IMC. The lenses are opaque around the edges with a clear view in the centre, which allows the pilot to see the flight instruments but not the external visual references.

to Barnoldswick, Settle and Lancaster before returning to Blackpool, including a diversion from the planned track and recovery to the next waypoint. It was to be a VFR flight, and the student and instructor had a detailed discussion on the forecast weather and METARs available for the area and made a visual assessment of the local conditions. It was agreed that the conditions were suitable for the flight, but plans were made for diverting using the lower ground and avoiding the higher terrain should the weather prove poor.

In reviewing the pilot's flight log, the instructor noticed that there were errors in the Minimum Safe Altitude (MSA) on three legs. One was corrected but the others were not, and the planned altitude on the accident leg was left as it was, which was below the MSA. The instructor authorised the flight and the student performed the pre-flight inspection before booking out with ATC. On the first leg from Blackpool to Barnoldswick, the pilot flew to the north of his planned track, to avoid poor weather in the area of Longridge, but remained clear of cloud and in sight of the surface and was able to regain a track for his first turning point. The planned route and the track flown are shown in Figure 1 with markers showing time and GPS height and groundspeed. Figure 2 shows an expanded view including the area of inadvertent flight in IMC.

On approaching Clitheroe, the pilot again saw weather that would not permit him to remain VMC and made a turn to the north. He could see Settle but, as he approached it, he was forced to adjust course again to avoid cloud. After completing the turn, he decided to carry out a practice diversion to Higher Bentham as part of the preparation for his upcoming skills test.

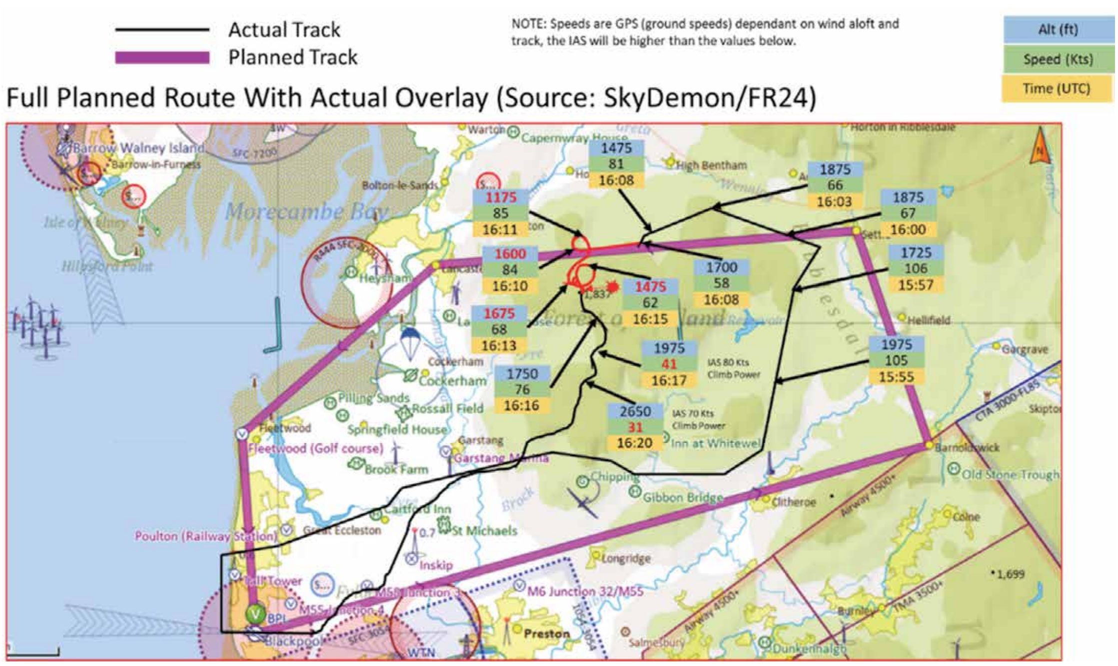

Figure 1

The planned route and actual track (courtesy SkyDemon and Flightradar24)

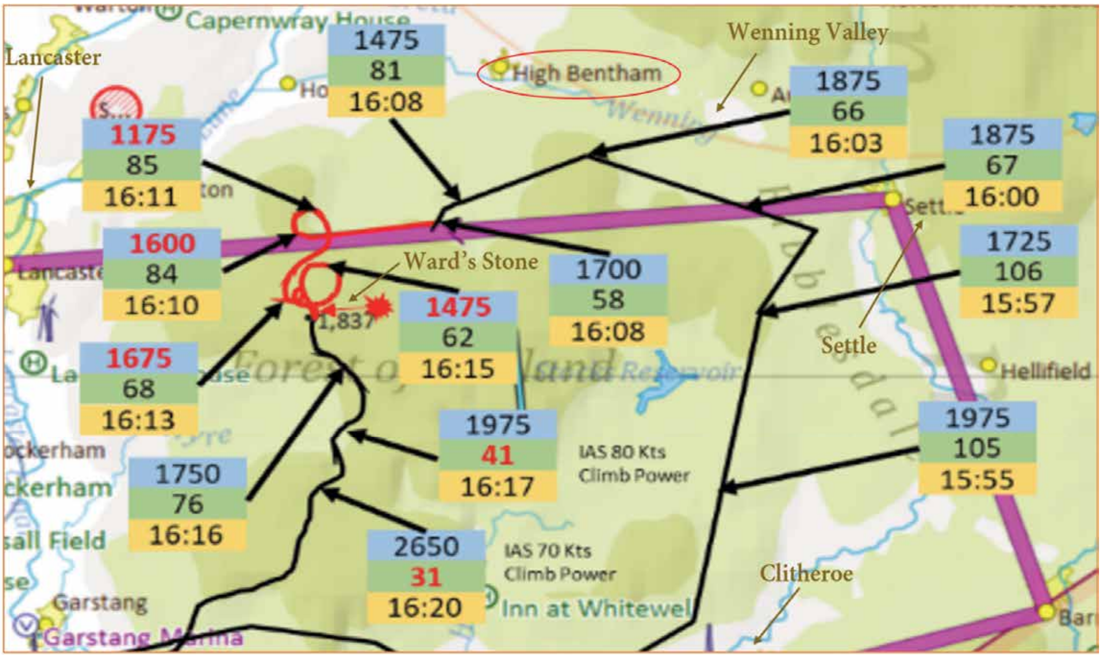

Figure 2

An expanded area of the route with inadvertent flight in IMC indicated in red

Flying north towards the low ground of the Wenning Valley, the pilot saw that the weather was unsuitable but also that there was blue sky and better weather conditions towards Lancaster, and so he decided to continue on a direct heading for there. The GPS track-following recorded GPS-derived height and groundspeed, which showed that the aircraft was at 1,475 ft and 81 kt at 1608 hrs. Shortly after this, the aircraft entered IMC, possibly due to the pilot's attention being focused within the cockpit, and, in accordance with his training, he commenced a 180° turn expecting to regain VMC. However, during the turn, the aircraft descended from 1,600 ft to 1,175 ft in a minute and turned through some 300°, with the pilot experiencing disorientation. Having recognised the loss of altitude, the pilot applied full power and intended to climb above 2,000 ft. He was aware that he was in the vicinity of a ground obstacle shown on the chart as Ward's Stone, which has an elevation of 1,837 ft.

At about this time, the aircraft's track-following showed it to be at 1,675 ft and 68 kt, and the pilot decided to carry out two 360° turns in order to allow him to stabilise his position and "gather his thoughts and intentions". Towards the end of the first turn, at the same altitude and still flying on instruments, the pilot saw the ground in close proximity and pulled up, avoiding it. Halfway around the second turn, at 1615 hrs, the altitude was 1,475 ft and the aircraft groundspeed was 62 kt. Between then and 1616 hrs, the aircraft flew close to Ward's Stone and the pilot again saw the ground. He took "evasive action", but the right main landing gear struck the ground. The impact caused damage to the windscreen and an initial loss of control, which the pilot immediately recovered. A 'MAYDAY' call was transmitted, which was relayed to Warton Radar by another aircraft, and a code of 7700 was set on the transponder.

The pilot was able to climb to 2,650 ft and, despite the loud airflow noise from the broken windscreen and open door, was able to follow the radar vectors provided by Warton Radar until VMC was regained and a landing back at Blackpool Airport was carried out.

Meteorology

Prior to the flight, the pilot and instructor had reviewed the weather using the current Met Office F214 and F215 charts (spot wind and low-level weather forecasts respectively), the latest TAFs and METARs, as well as other weather applications. They had agreed that the weather was suitable for the intended flight and had agreed contingency plans should the pilot encounter any weather-related problems.

The Blackpool Airport TAF and METARs covering the duration of the flight were:

TAF

TAF EGNH 081405Z 0815/0820 24010KT 9999 SCT015=

METARs

METAR EGNH 081520Z 23007KT 9999 FEW025 BKN039 20/18 Q1021=
METAR EGNH 081550Z 24008KT 9999 FEW013 BKN031 19/17 Q1021=
METAR EGNH 081620Z 27007KT 9999 FEW013 BKN030 19/17 Q1021=
METAR EGNH 081650Z 26007KT 9999 BKN028 18/17 Q1021=

The information shows that at Blackpool during the time of the flight there were Few or Scattered clouds below the MSA for the route.

Aircraft information

During the impact with the ground, the aircraft was damaged. The right main landing gear was disrupted and the top of the windscreen broke and detached. A significant increase in cabin noise made two-way radio communication almost impossible. The cabin noise was due to the wind caused by the combined effect of the damaged windscreen and the passenger door being blown open. The damage is shown at Figure 3 below.

Analysis

The pilot deviated from his planned route to avoid areas of weather that would have prevented him from maintaining VMC but at the same time stayed as close as possible to the original routing. During the third, west-bound, leg, the pilot inadvertently entered IMC and followed his training to make a 180° turn to regain VMC. His only experience of flying by sole reference to instruments was two flights of dual instruction in VMC using ‘Foggles’. During the ensuing flight in IMC he became spatially disorientated and, despite his best efforts, lost height and struck the ground, but he was able to regain control and climb. Having declared an emergency, he was assisted by Warton Radar, relaying initially through another aircraft, to regain VMC. Given his lack of IMC experience, he was fortunate to recover the damaged aircraft back to Blackpool Airport.

Figure 3
Aircraft damage caused by the impact with the ground

In its report into the incident, the Declared Training Organisation (DTO) identified four potential causal factors, which were:

- *'Setting of Minimum Safe Altitudes (MSA) – this was marked incorrectly by the student, the instructor corrected the error on the leg that caused the event, but the student did not adjust the planned altitude level – this remained at 2000ft and thus was 500ft below the MSA selected. The student twice recalls an attempt to recover beyond 2000ft, the radar track as previously shown indicates an altitude of between 1475ft and 1750ft, which indicates that the attempt to climb was incomplete at point of incident.*

- *Non-diagnosis of the serious nature of the cloud cover in the run up to the incident phase. After departure, cloud cover to the south of Blackpool, cloud cover over Barnoldswick causing an early turn near Clitheroe, the cloud cover preventing transit of the Wenning Valley, were all indicators and markers to the PIC about the deteriorating condition of the weather in the region and the need to execute an RTB in VMC conditions.*

- *Low hours and pilot inexperience of the conditions, likely delayed decision making and led to spatial disorientation, resulting in an un-commanded decent.*

- *Unconscious bias. There are 4 types of unconscious bias, in this instance the specific aspect is confirmation bias. Confirmation bias is the human trait whereby we seek to identify aspects around us that prove a hypothesis, understanding or perception we have. In this instance it is believed the pilot was seeing several instances of deteriorating bad weather, immediately followed by an opportunity to continue sighting good weather or blue skies, thus confirming the perception that continuing the flight was safe.'*

Conclusion

The Controlled Flight into Terrain (CFIT) was the result of an inadvertent entry into IMC whilst the pilot was attempting to complete a solo cross-country navigation exercise. The possible causes for the accident were identified by the DTO as being: the inexperience of the student pilot; flying below MSA; the pilot not recognising a general deterioration in the weather conditions; and the pilot expecting the weather to improve because it had done so earlier.

Safety action

The Declared Training Organisation proposed to introduce the following Safety Actions:

- The club would reinforce / refresh the required approach to reviewing weather data prior to departure to ensure consistency across the PPL, Instructor and Student populations.
- An MSA and Maximum Elevation Figure (MEF) refresher training pack would be developed and issued to all club members. Training would be given to all students in a ground-based environment prior to the navigation phase of the PPL course. This would supplement the normal PPL training and navigation exam.
- Selection of MSA and MEF would be more diligently reviewed by instructors, any errors would be discussed in detail between the pilot and instructor, corrections would be clear and re-enforced, and the planned altitudes would be adjusted accordingly.
- The Club would consider the construction of a standard example map for use as a training aid.
- Unconscious bias (confirmation bias). Human Performance and Limitations (HPL) and Human Factors (HF) refresher pack would be updated to include a section on the effect of unconscious bias and how to mitigate against it. A case study of this event would be included in the club HPL and HF refresher pack.
- Feedback would be given to Blackpool ATC on the visibility of the green ‘cleared to land’ light. A note would be issued to all members on the meaning of the lights and where to look in the event of radio failures or difficulties.
- The Club would undertake a ground based one-hour review for each student, led by the safety manager, briefing the content of this event as part of a groundschool activity.

Accident

Aircraft Type and Registration:	Ikarus C42 FB80, G-CFHP
No & Type of Engines:	1 Rotax 912-UL piston engine
Year of Manufacture:	2008 (Serial no: 0805-6972)
Date & Time (UTC):	13 September 2020 at 0900 hrs
Location:	Porthtowan, Cornwall
Type of Flight:	Training
Persons on Board:	Crew - 1 Passengers - 1
Injuries:	Crew - None Passengers - None
Nature of Damage:	Nose landing gear leg, both wings and engine cowling damaged
Commander's Licence:	Private Pilot's Licence
Commander's Age:	71 years
Commander's Flying Experience:	6,516 hours (of which 2,916 were on type) Last 90 days - 15 hours Last 28 days - 5 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

Synopsis

During the latter stages of a practice forced landing (PFL), the right landing gear wheel spat struck the perimeter fence of the airstrip. The aircraft turned sharply right and struck the ground, causing extensive damage. Both those on board were uninjured and were able to exit the aircraft unaided. Safety action was taken to stress the importance of going around should it appear that a PFL would be unsuccessful.

History of the flight

The commander was a flight instructor and examiner and was conducting a test to renew the lapsed licence of the student. After a successful upper air exercise, the aircraft was returning to Perranporth Airfield. A parachute jump was scheduled at Perranporth and therefore the return to the airfield was delayed. The commander decided that a demonstration of the 'Beat Method' for a PFL would be of value. The 'Beat Method' involves flying a figure of eight pattern downwind of the landing site until sufficient height is lost to position the aircraft on a normal glide approach.

The commander chose to use a private airstrip at Porthtowan for the PFL demonstration and the intention was to fly the procedure to a go-around. The procedure was commenced from 1,500 ft agl, approximately one third of a nautical mile from the downwind threshold for Runway 21 at Porthtowan. The commander considered the aircraft was high for the range remaining to the airstrip and so immediately lowered full flap to steepen the descent. He made a left turn, followed by a right turn and then another left turn onto what he described as a right base leg for the airstrip. The commander stated that "the steepening of the glide angle at this point subconsciously caused my focus to shift from a point one third into the runway (the initial aiming point) to an area much closer to the downwind threshold." The base leg track was into the wind, which was from approximately 200° at 5 kt. From this track a turn of only 20° to the right was required to align with the runway.

A set of domestic power cables runs past the threshold of Runway 22 (Figure 1) and these were at right angles to the aircraft's into-wind track.

Figure 1

Power cables from approximately where the aircraft came to rest

The commander's intent was to turn onto the runway track after crossing the cables. The commander stated: "We cleared the cables easily but, being a little lower than I had intended, delayed the right turn until completely clear of them, which meant the aircraft ended up a few metres to the south of the runway requiring a further right turn to align with the runway." The commander estimated that the aircraft crossed the cables between 30 and 40 ft agl. It was his opinion that the wind was a little stronger than he had anticipated and so the aircraft was not gliding as far as he originally expected. Therefore, the aircraft crossed the cables lower than intended. The commander stated that by this stage of flight his focus was so intense that he felt unaware of the other person in the cockpit.

After clearing the wires, the commander made the right turn towards the airstrip using 30 to 35° angle of bank. During the turn the right landing gear struck a fence, approximately 5 ft tall, at the edge of the airstrip. The fence arrested the aircraft's flight, turned it to the right through 90° and caused it to strike the ground heavily, damaging both wings, the engine cowling and the nose landing gear. Neither occupant was injured, and both were able to exit the aircraft unaided. The approximate aircraft track and aircraft final position is shown at Figure 2.

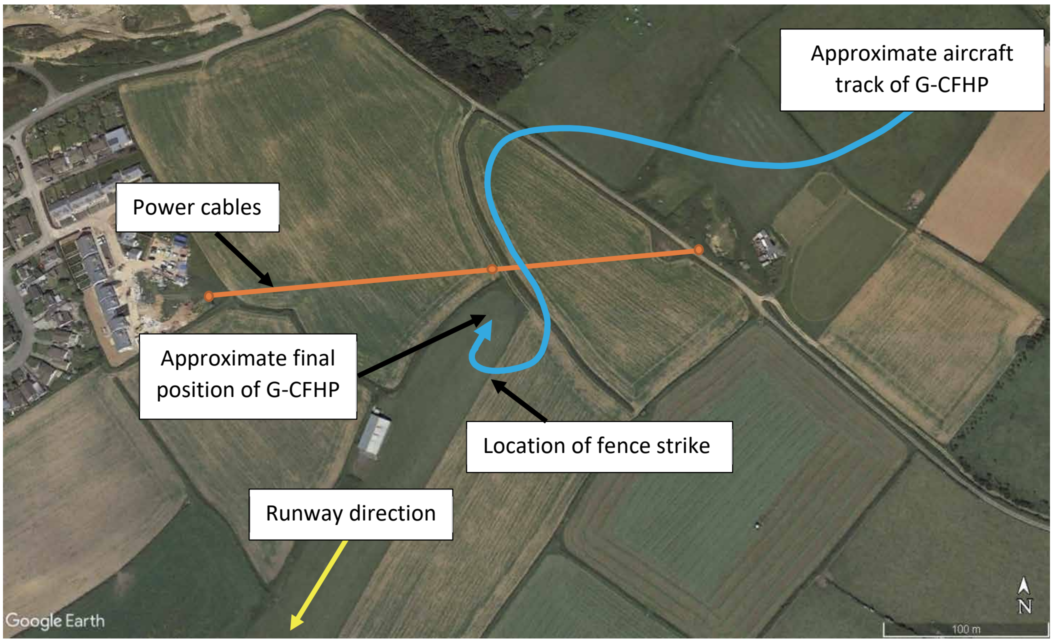

Figure 2

Approximate aircraft track

Figure3

View along Runway 03 showing boundary fence

Airfield information

Porthtowan is a private grass airstrip in Cornwall. It has one runway, Runway 03/21, which is approximately 500 m long.

Personnel information

The commander was familiar with the airstrip at Porthtowan and had operated there many times. He was aware of the cables that cross close to the runway 22 threshold. Once established on the base leg track the commander could clearly see the cables.

During the demonstration the student became aware that the flight path was unusual. He believed that had he been in control and in the same situation the instructor would have directed a go-around. However, the student had confidence in the commander and felt it was inappropriate to call for a go-around himself.

Cognitive tunnelling

Cognitive tunnelling is an inattentional blindness phenomenon in which the observer's attention is focused on specific items or tasks rather than on the present environment. For example, while driving, a driver focused on the speedometer and not on the road may be suffering from cognitive tunnelling.

The commander considered that he had experienced cognitive tunnelling during this event.

Organisational information

The British Microlight Aircraft Association (BMAA) Microlight Instructors and Examiners Guide gives the following advice for the conduct of forced landings:

> *'The following notes are applicable to all forced landing patterns without power:*
>
> - *The initial aiming point should be positioned between approximately one half and one third of the way into the chosen landing site.*
> - *The initial aiming point should be kept in view throughout the procedure.*
> - *The angle of bank should not normally exceed 30° in any manoeuvres completed during the procedure.*
> - *The aircraft should normally be established on final approach at a similar height to that used for a glide approach in the normal airfield circuit pattern.*
> - *Once established on the final approach and the initial aiming point is assured the actual touch down point should be brought towards the threshold by the appropriate technique.'*

A BMAA Examiner was asked for an opinion on the height at which an aircraft should be established on a final approach when gliding. They considered that an aircraft should be wings level on a final approach by 200 ft agl and that it would be unusual to manoeuvre below that height. The BMAA Instructors and Examiners Guide does not give specific heights by which pilots should be established on final approach or by which they should initiate a go-around.

Analysis

At the start of the demonstration the commander considered that the aircraft was high for the distance to the airstrip and he therefore selected full flap. The commander stated that the '*appropriate technique'* referred to in the BMAA Instructors and Examiners Guide to bring the touchdown point towards the threshold was principally use of flap. The early selection of full flap steepened the glide angle significantly and removed the option of using flap to modify the flight path on final approach.

Once established on the into-wind track the commander began to focus on the power cables. He was aware that the flight path was lower than planned but was confident that the aircraft would clear the cables by a safe margin. In retrospect he was aware that either an earlier turn to final and a landing approximately 200 m into the runway or a go-around at any point would have avoided the accident. However, he considered that he became so focused on avoiding the cables that he experienced cognitive tunnelling and ceased to consider the option to go-around.

As the aircraft cleared the cables it was already at a low height. The commander felt that the margin was safe, and his focus moved to landing near the threshold. Delaying the turn to remain wings level while crossing the cables had positioned the aircraft left of the intended approach track. Therefore, a turn through a greater number of degrees than intended was required to reach the airstrip. This turn was carried out with approximately 35° angle of bank at a height of less than 40 ft agl. This manoeuvre would have increased the rate of descent and the commander's workload. The commander believed the aircraft would clear the fence around the airstrip but the right landing gear struck the fence and the aircraft landed heavily.

Conclusion

The commander's attention became focused on the power cables to the extent that he probably experienced a cognitive tunnelling effect. Therefore, he did not recognise the inappropriate nature of his flight path and did not take the corrective action of initiating a go-around. During the turn to final at low height the aircraft struck a fence, arresting its flight and causing it to land heavily.

Safety actions

The BMAA will review the advice to instructors regarding the conduct of PFLs, with particular emphasis on early initiation of a go-around if the plan is not working as expected.

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 December 2020 - January 2021

27-Jul-20 **Yuneec H520** Brae, Shetland

The UA was being used to film a fire when it lost power and fell to the ground inside the emergency services cordon. The UK agent identified the likely cause of the sudden power loss was the battery moving in its holder. The manufacturer has developed an additional clamp to improve the security of the battery.

23-Sep-20 **DJI Matrice 200 V1** Perth, Perthshire

During a training flight the UA motors suddenly shut down and the UA dropped into trees from a height of 390 feet. The data contained the following errors 'Barometer Dead in Air', 'Not Enough Force' and 'ESC Error'. The insurers disposed of the UA so no examination was possible to determine the cause.

27-Sep-20 **Parrot Anafi** Leeds, West Yorkshire

The propeller detached in flight and the UA was damaged on impact with the ground.

16-Nov-20 **Itchenor** Goodwood Aerodrome, West Sussex

During a test flight, whilst the UA was being controlled from a remote location, communications were lost due to the ground antenna not covering the full flight area. The on-site safety pilot took control but, whilst attempting to change to 'Position Mode' to land the UA, inadvertently handed control back to the remote controller. The remote controller's throttle was set to 50%, which is insufficient for the UA to maintain altitude. The UA descended, landed heavily and was damaged. The operator is reviewing its operating procedures, software and hardware.

19-Nov-20 **DJI Phantom** Colchester, Essex

Approximately ten minutes into the flight the battery was seen to fall from the UA. The UA lost power and crashed.

1-Dec-20 **DJI Phantom 4 RTK** Morley, West Yorkshire

Shortly after take off, at a height of 55 metres, the UA began to spin and descended, out of control, until it struck the ground. The pilot attributed the accident to a possible propeller failure.

2-Dec-20 **DJI Inspire 2** Oakham, Rutland

While conducting aerial filming, the UA struck overhead power lines and fell to the ground, incurring substantial damage.

Record-only UAS investigations reviewed December 2020 - January 2021 cont

7-Dec-20 **Yuneec H520** Shotts, North Lanarkshire

The UA took off with a fully charged battery to survey some woodland. As it transited to the start point of the survey the pilot noticed the battery level diminishing quickly, and commanded the UA to return to the landing site. The battery charge continued to decrease to the point that the UA lost power before it reached the landing site, and it struck the canopy of the woodland. There was extensive damage to the UA.

9-Dec-20 **Yuneec H520** Port of Cromarty Firth, Ross and Cromarty

The link between UAS and ground controller was lost, and the UA drifted out to sea and it was not recovered.

13-Dec-20 **DJI Matrice 210 V2** Mansfield, Nottinghamshire

The UA, which had new batteries, suddenly fell to the ground approximately 52 seconds into a flight.

15-Dec-20 **DJI Inspire 2** Canary Wharf, London

Whilst filming over the water at Canary Wharf, the UA suddenly lurched forward. The operator made an input to arrest this movement, but the UA moved rapidly backward, struck a nearby building, and descended rapidly landing heavily on the roof of a covered walkway. The UA was severely damaged.

17-Dec-20 **DJI Mavic Pro 2** Bath, Somerset

Manual control was lost during landing. The UA collided with a nearby wall and fell to the ground, causing damage to its propellers.

22-Dec-20 **DJI Mavic 2** Tursdale, Durham

On takeoff, just prior to pre-flight control checks, control of the UA was lost and it collided with a fence.

26-Dec-20 **Holy Stone HS720E** Cambridge

The UA was reported missing during a flight in fields near to Cambridge Airport. The UA could not be found

21-Jan-21 **DJI Mavic 2 Enterprise** St Ives, Cornwall

The UAS was being flown over the sea when the operator observed a battery warning message. The operator tried to bring the UA back to the takeoff point but, when over land, it lost power and fell to the ground from a height 10 m. The operator had avoided overflight of people on the beach when bringing the UA back to the takeoff point.

Record-only UAS investigations reviewed December 2020 - January 2021 cont

26-Jan-21 **DJI Matrice 300 RTK** Carrington, Manchester

This was the first flight for the UAS. It suffered a hardware failure, possibly a motor, 20 minutes into the flight and fell approximately 50 ft into a wooded area.

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:	Agusta A109E, G-ETPJ
Date & Time (UTC):	2 July 2020 at 1510 hrs
Location:	Boscombe Down Airfield, Wiltshire
Information Source:	Aircraft Accident Report Form and further enquiries by the AAIB

AAIB Bulletin No 1/2021, pages 49 and 50 refer

Following publication the following corrections were made to the report.

The fourth sentence in the synopsis on page 49 should read:

> The cable was part of a design change that was made whilst the helicopter was on the UK military register operated as Military Registered Civil Owned Aircraft (MRCOA) subject to oversight by the UK CAA.

Not as originally stated: The cable was part of a design change that was made whilst the helicopter was on the UK military register before being approved by a Supplementary Type Certificate (STC) when the helicopter was transferred to the civil register.

The last sentence of the first paragraph of the Flight Test Instrumentation section on page 50 should read:

> When the helicopter moved onto the civil register the design was reviewed by an approved organisation and a STC was issued by the EASA.

Not as originally stated: When the helicopter moved onto the civil register the design was reviewed by an approved organisation and a STC was issued by the UK CAA.

The online version of the report was corrected 11 February 2021.

BULLETIN CORRECTION

Aircraft Type and Registration:	Pitts S-2A Pitts Special, G-ODDS
Date & Time (UTC):	24 August 2019 at 1304 hrs
Location:	Stonor, Oxfordshire
Information Source:	AAIB Field Investigation

AAIB Bulletin No. 2/2021, page 11 refers

The report first published on 21 January 2021, contained the sentence on page 11:

> In April 2019, the aircraft had a 50-hour maintenance check and the devices were fitted to the cables during the check.

To provide clarity that it was not the maintenance organisation that fitted the devices, this sentence has been changed to:

> In April 2019, the aircraft had a 50-hour maintenance check and, during the check, the devices were found already fitted to the rudder cables.

The online version of this report was corrected on 28 January 2021.

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 Union 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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