Accident

Aircraft Type and Registration:	UAS Malloy Aeronautics T150
No & Type of Engines:	8 Electric motors
Year of Manufacture:	2023 (Serial no: 120)
Date & Time (UTC):	27 June 2023 at 1443 hrs
Location:	Field in South Scarle, Lincoln
Type of Flight:	Training
Persons on Board:	Crew - None Passengers - None
Injuries:	Crew - N/A Passengers - N/A
Nature of Damage:	Destroyed
Commander's Licence:	General Visual line of sight Certificate (GVC)
Commander's Age:	45 years
Commander's Flying Experience:	150 hours (of which 2 were on type) Last 90 days - 5 hours Last 28 days - 5 hours
Information Source:	AAIB Field Investigation

Synopsis

Whilst being operated in a manual flight mode, the unmanned aircraft breached the geofence and changed to an automated flight mode. In response, the remote pilot reduced the throttle and changed back to the manual mode. Control of the aircraft was lost because the mode was changed at a low throttle setting and the subsequent actions to regain control were unsuccessful. The aircraft struck the ground and was destroyed.

The operator no longer uses the manual mode and has promoted the use of standardised phraseology between the ground control station operator and the remote pilot. Further action has been taken to consider and apply a suitably sized geofence for each operational flight.

The Operation Safety Case on which the Civil Aviation Authority (CAA) granted a Specific Category Operational Authorisation were missing definitions and procedures for the use of geofences and actions to be taken in the event of a breach. A Safety Recommendation has been made to the CAA as these omissions have further effect as the use of a geofence is widely used as a mitigation for several other operational risks.

History of the flight

The Remote Pilot (RP) was undertaking a skills currency flight using a Malloy Aeronautics T150 unmanned aircraft and was assisted by a Ground Control Station (GCS) operator. The RP and GCS operator were in two-way communication via radio. The RP was flying circuits in Stabilised flight mode (STAB mode) at a training ground. It is a remote site on farmland used by the organisation he was contracted to fly with as an R&D and training pilot. The geofence for the flight was 40 m high by 300 m radius with the centre on the takeoff point (Figure 2). The dimensions of the geofence were not considered by the RP and GCS operator prior to the flight but accepted as a standard training envelope.

The GCS operator noticed the aircraft was approaching the upper limit of the flight geography zone within the geofence and he informed the RP using terminology not immediately understood by the RP. The RP was aware that the aircraft was turning to the right and climbing quicker than he had expected. Shortly afterwards the aircraft breached the upper limit of the geofence and reverted to an automated Return to Launch (RTL) flight mode. The RTL automation initially commanded the aircraft to climb, which the RP instinctively counteracted by reducing the throttle. The GCS operator informed him that RTL mode was engaged, and the RP changed the flight mode, by cycling the three-way flight mode selector switch on the handheld transmitter, to LOITER and then back to STAB mode.

The aircraft diverged from level flight and was seen to follow an erratic flight path unfamiliar to the RP, during which it achieved a maximum pitch of -41° and -60.9° of roll. To regain control the RP increased the throttle to 100% which caused the aircraft to overcorrect, and it then pitched to 85.3° with 60° of roll before descending rapidly from a height of 37 m. The RP realised he could not regain control and switched to an automated mode (LOITER mode) but by this time the aircraft was heading towards the RP's ground position and he decided to close the throttle, bringing it to the ground (Figure 1). Twelve seconds had passed from the geofence breach before the aircraft struck the ground approximately 50 m from the RP's position and within the horizontal boundary of the geofence (Figure 2).

Figure 1

Malloy T150 unmanned aircraft at the accident site

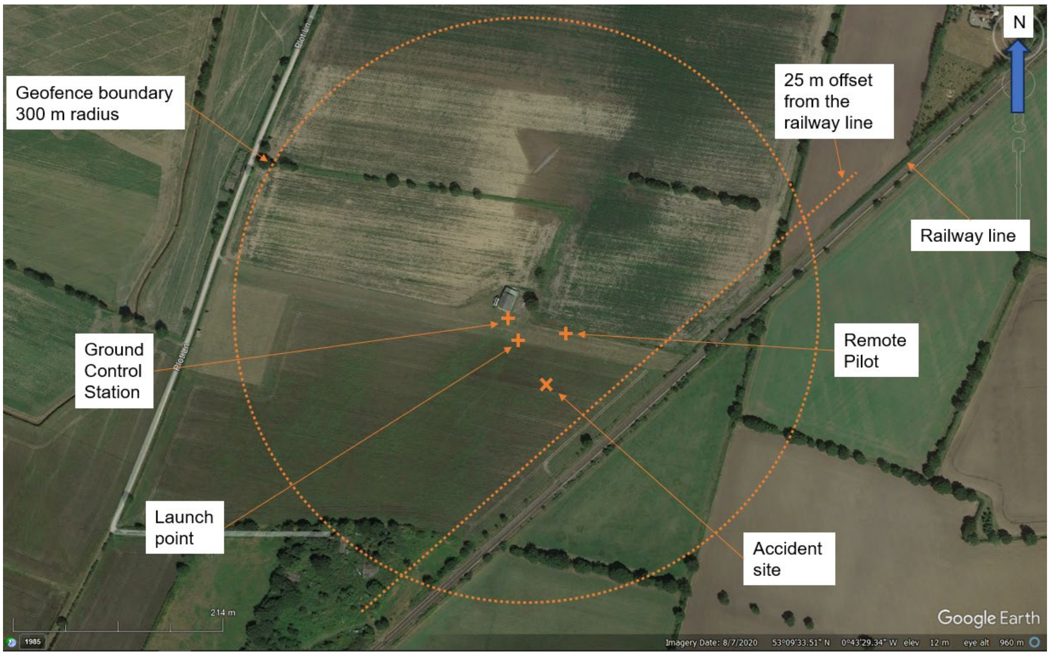

Figure 2

Accident site and geofence

Recorded information

Data downloaded from the UA showed that at 1445:56 hrs (local) the aircraft entered RTL mode (Figure 3) and the throttle input was recorded as having reduced to 2.6% from an RP input; this had no effect in RTL mode. The mode then changed to LOITER for approximately 600 ms before going back to STAB where the throttle increased to 100% in less than 1 sec. A large roll input was recorded after which the mode was changed to LOITER. The aircraft deviated from normal flight attitude and was not under control. The throttle was recorded as reducing to zero. The aircraft then pitched up but as it was inverted, it struck the ground.

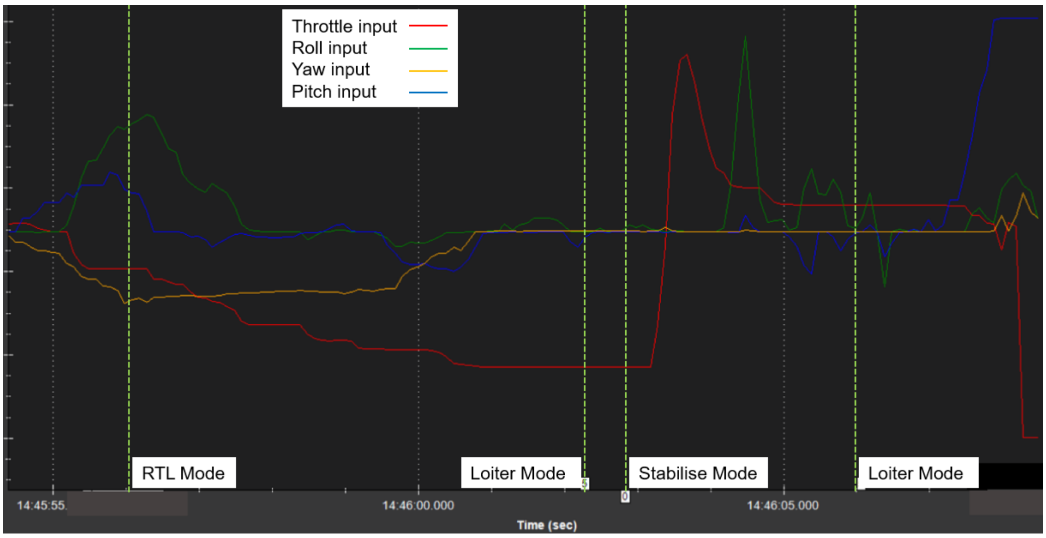

Figure 3

Pilot inputs

Aircraft information

The Malloy Aeronautics T150 is a military standard, cargo carrying unmanned aircraft capable of lifting a payload of 68 kg, has a maximum takeoff mass of 123 kg and produces 240 kg of thrust from its eight electric motors. The aircraft can be operated in various flight modes from manual flying with little automated assistance to fully automated pre-planned missions with minimal RP input required.

RP transmitter

On the accident flight the RP operated the aircraft with a FrSky Taranis X9D plus transmitter (Figure 4) and was supported by a GCS operator. The transmitter operates on 2.4 GHz and has a variety of customisable switches and features. The left stick controlled the throttle and yaw with the right stick for pitch and roll. It is possible to adjust the length of the sticks to suit individual operators. The transmitter is fitted with a three-way toggle switch which enabled the RP to manually change between a selection of the pre-programmed flight modes. There are 20 different automated flight modes available within the aircraft firmware which can be combined with the automated mission flight profiles. On the accident flight the selectable flight modes were Altitude Hold (ALT HOLD), STAB and LOITER mode.

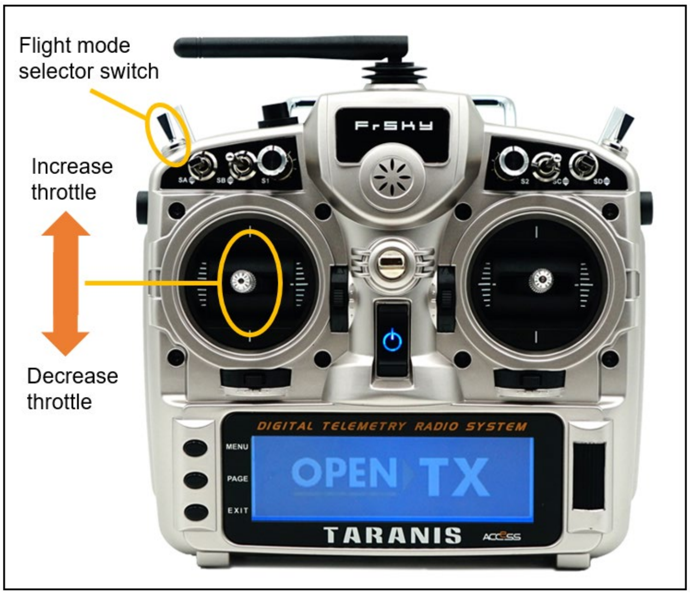

Figure 4

FrSky Taranis X9D plus transmitter

Flight modes

LOITER mode is a highly automated flight mode with the vertical and horizontal position of the aircraft controlled by the software. All the onboard sensors and GNSS receivers are operational. ALT HOLD mode allows manual commands in roll and pitch and is commonly used when the GNSS signal is lost. Translational speeds are higher than in LOITER mode but vertical speeds are limited. STAB mode is a reversion mode when multiple sensors (lidar, barometers) and both GNSS units are not functioning. The RP has full authority in all directions and access to the full 240 kg of available thrust. The probability of the aircraft entering this mode is remote due to inbuilt redundancy. The operator's RPs frequently flew in this mode to retain a high manual skill level and in case of an emergency during the R&D work they were undertaking. RTL mode is a fully automated mode which is engaged when the geofence is breached. The initial command is to climb 2 m then transition in a straight line to the launch point before landing. In this mode the RP inputs on the transmitter (Roll, pitch, yaw and throttle) have no effect.

Ground Control Station

To assist the RP a GCS operator is employed to monitor the continuous data feed from the aircraft and provide warnings, information and updates via radio headsets. The GCS laptop uses the open source ARDU Pilot Mission Planner software and the user interface is shown in Figure 5.

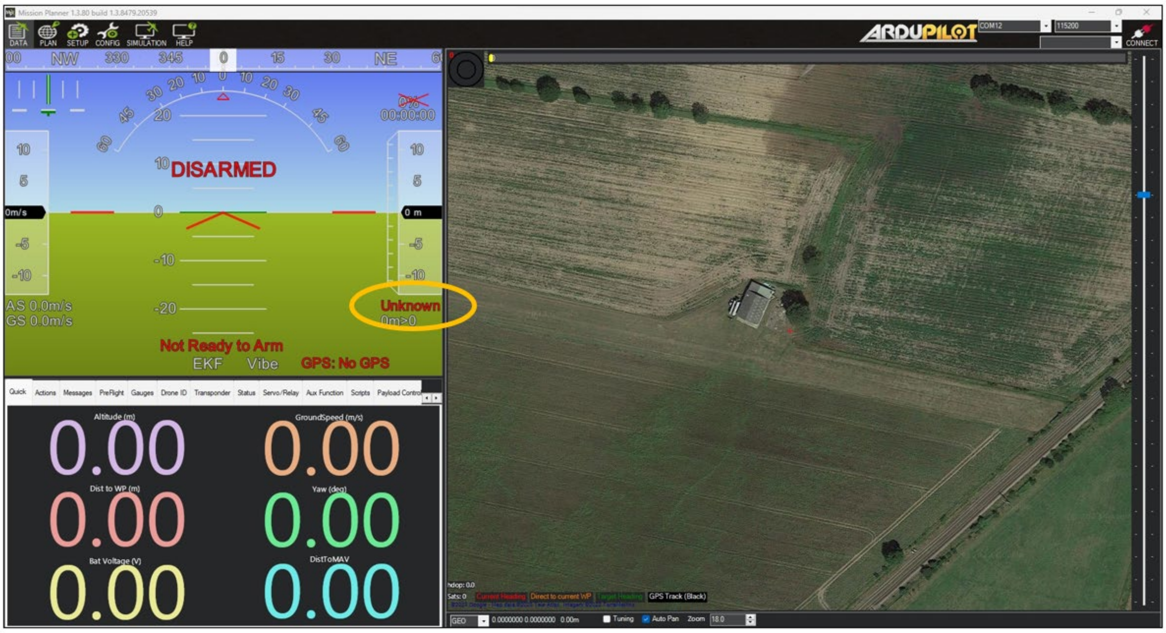

Figure 5

ARDU Pilot Mission Planner interface

The display in the top left shows the primary flight display similar to a manned aircraft and the highlighted text: 'UNKNOWN', is the flight mode caption. The software has an audible alert when the flight mode changes and the text flashes to white before returning to red. It was reported that these audible alerts were disabled for the accident flight. The lower left part of the interface contains 'Control and Status' values for various flight parameters such as battery level, altitude etc. The right side of the screen can be configured for either a map view or video feed.

Personnel

The RP was an experienced unmanned aircraft pilot who had been flying for many years. He was a member of the British Model Flying Association and the Large Model Association and had been flying the T150 for two years. He was subcontracted to the operator as an instructor and R&D pilot and held an A2 Certificate of Competency (CofC) and a General Visual line of sight Certificate (GVC).

The Ground Control Station (GCS) operator was also a qualified UA pilot with an A2 CofC and a GVC certificate and was experienced on multiple UA types. He held a company authorisation to be a mission commander and a GCS operator.

There were four other involved people at the operating site, but none were actively engaged with the aircraft operation on the accident flight.

Operating Safety Case

The aircraft was being operated in the Specific Category[1] under a CAA Operational Authorisation (OA) granted on 30 May 2023. The OA referenced the Operating Safety Case (OSC) document which included an Operations Manual (Volume 1 version 1.3), a Technical Ability document for the T150 (Volume 2 version 1.3) and Safety Risk Assessments (Volume 3 version 1.5). The OSC covered all aspects of the operation of the aircraft within the boundaries of the pre-defined work package that the prime contractor was engaged to provide. The operator on the accident flight was subcontracted to a prime contractor to provide training and test pilots for a development programme.

Volume 1 section 6 details the integrated organisational structure of the prime contractor and the operator for the purposes of the development programme. The contact details, licenses and types flown for many RPs but not the subcontract RPs details and skills. The section does not mention the use of subcontract RPs and only the Chief Pilot has the Malloy T150 listed in '*Types*'.

Volume 1 section 9 Competency and Qualification Requirements defines the overall training plan for an RP to convert to the T150 from another type. Ground and flight training is covered and specifically includes flight modes (LOITER, ALT HOLD & STAB) and emergency handling. It refers to an additional training annex – *'Disparate Remote Autonomous System Training Plan'* in which ground and flight school syllabi are detailed. RTL logic and safety settings are listed although there is no specific reference to operating within a geofence.

Volume 1 section 9.3 is specific to maintaining currency of flying skills for RPs and is defined as two hours every 90 days on any UA (not necessarily a T150). There are no other specific requirements and '*training should be focussed in areas of self-identified weakness*'.

Footnote

1 Unmanned Aircraft System Operations in UK Airspace - Guidance (caa.co.uk) – CAP 722 section 2.2.2. [Accessed June 2023].

Volume 1 section 14.1 details the area of operation at the South Scarle site. Currency and competency flying are listed but '*no flights within 25m of railway on E-side*' are allowed. No vertical or over flight restrictions are defined.

Volume 1 section 25.5 describes the software functionality of programming geofences and the interaction between the ADRU Pilot software and the Special Mission Computer. Figure 6 taken from the OSC, is the Safe Airspace Volume (SAV) diagram that RPs and mission commanders '*must understand*' during flight planning. The origin of the diagram is from the graphical representation of the Joint Authorities for Rulemaking of Unmanned Systems (JARUS) Specific Operations Risk Assessment (SORA) Semantic Model to ensure a common usage of terminology for risk assessments. There are no specific requirements or information on how to define a suitable size related to the flight purpose, nor any RP procedures in the event of a geofence breach despite the statement that a '*breach of the Operational volume will require emergency action*'. The operators understanding of the contingency volume is the maximum operating volume allowed under their OA which was 400 ft (120 m) above surface level and 500 m from the RP. The geofence on the accident flight was considered to be the flight geography volume.

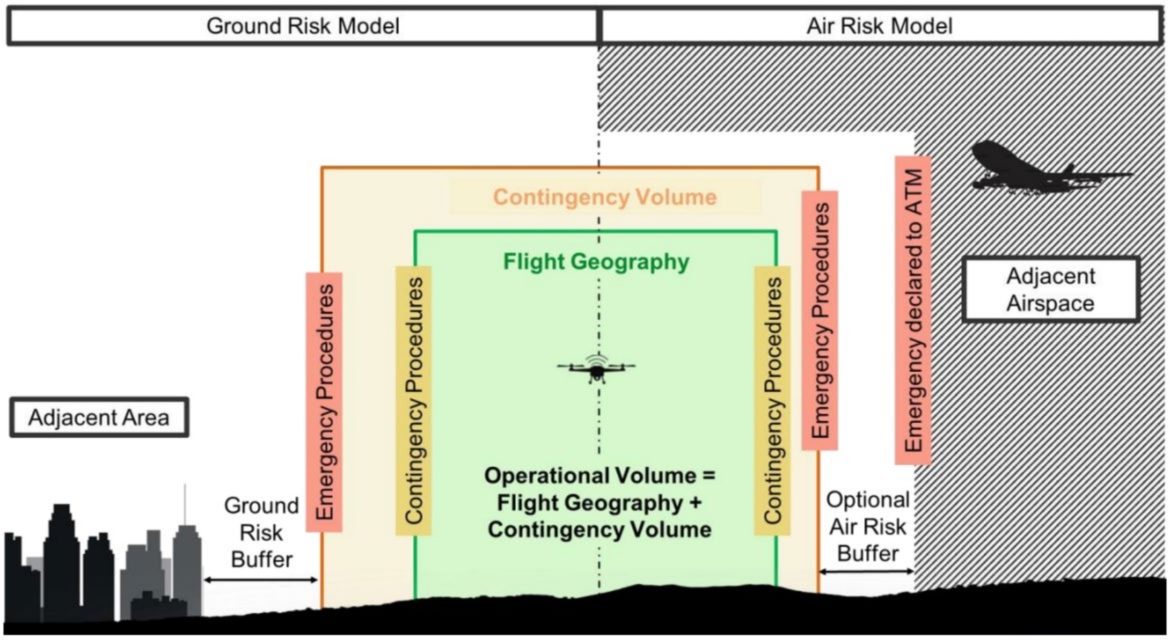

Figure 6
SAV model / JARUS SORA Semantic Model

Volume 1 appendix B are the applicable checklists to be used before, during and after a flight. A search of the checklists for items related to the geofence returned the only result in the '*Power On and Safety Checks*' in which the geofence is to be ENABLED and '*set appropriately*'. No parameter is included to qualify the appropriateness of the geofence set.

Volume 1 appendix B also includes all the Emergency Checklists and these were reviewed to identify if any could have been appropriate during the accident flight because a breach of the operational volume of the geofence will require '*emergency action'*. No Emergency Checklist could be found that was applicable for a geofence breach.

Volume 2 section 5.5 T150 Positioning, Navigation and Guidance states that in the event of a geofence breach the aircraft can be configured for the following actions:

- Land and report to GCS.
- RTL and report to GCS.
- Report to GCS only.

The geofence setup procedure refers to Volume 1 section 4.10 but Volume 1 section 4 is the Safety Statement from the Accountable Manager. No geofence setup procedure was found elsewhere in the OSC.

Volume 2 section 7 details the Emergency Recovery or Safety Systems and that the geofence is to be used for every flight to ensure the aircraft does not stray beyond the planned flight area including the maximum permissible altitude. In the event of a breach, the aircraft will be instructed to RTL or land at the RPs discretion.

Volume 3 of the OSC contains all the risk assessments and their mitigations for the specific operations that the operator planned to undertake. There are no risk assessments for a geofence breach or for a loss of control inflight. The most applicable risk assessment for the accident flight was Risk 4.9 'Flyaway – Air' and is described as '*an undesired flight trajectory and/or uncontrolled descent* [that] *could cause the aircraft to potentially exit segregated airspace and collide with another UAS or a manned aircraft or impact property causing damage, impact a person or animal causing serious injury or fatality*.' The '*During Operations*' mitigations for this risk is that the geofence will prevent the flyaway and that the flightpath is to be monitored by direct visual contact.

There are six risk assessments in which the use of a geofence is used to mitigate the impact[2]. In all cases the geofence is to be used to either maintain the aircraft within the designated airspace or to initiate the automated RTL mode.

Analysis

The accident flight

The RP, with the support of a GCS operator, was conducting a skills currency flight and flying circuits in a manual flight mode when he penetrated the vertical limit of the geofence. The STAB flight mode did not use any of the automated systems to aid the pilot and gave him full authority over throttle and speed in all the flight axis. The size of the geofence was 40 m high and 300 m radius centred on the takeoff point which was a standard size for training and no action was taken prior to the flight to consider if it was appropriate.

Footnote

2 See Appendix - Risk assessments using a Geofence to mitigate the impact.

The GCS operator verbally warned the RP over the two-way radio just before the geofence was penetrated but did not use terminology the RP instantly recognised. The audible alerts on the GCS ground station had been disabled which the RP could have heard directly over the radio. The operator acknowledged that in the future the audible alerts must be enabled on the GCS ground station and that standardised phraseology should be used between the GCS operator and the RP. When the aircraft penetrated the geofence the flight mode automatically changed to RTL and commenced an initial climb of 2 m.

As the aircraft approached 40 m agl the RP was already reducing the throttle and as the aircraft climbed further in RTL mode it was reduced to a minimum of 2.6% to counteract the climb. The GCS operator alerted the RP of the mode change to RTL and the RP cycled the flight mode switch on the transmitter from STAB to LOITER and back to STAB. This cancelled the RTL mode and returned the aircraft to the manual STAB mode but with only 2.6% throttle applied. The RP stated that as he was aware that the aircraft had penetrated the geofence and he saw no need to allow the aircraft to RTL. By cycling the mode switch, he could regain control of the aircraft and continue with the flight.

The aircraft was not able to maintain stable level flight with such a low throttle setting and immediately descended with roll which the RP countered by applying full throttle. This was followed by a large roll input. The aircraft is capable of 240 kg of thrust but only weighed 55 kg as there was no payload attached for the training flight. This abundance of thrust resulted in the RP over correcting the roll attitude and the aircraft further departing controlled flight. Upon reflection the RP considered that it was unusual that he had applied so much throttle in such an uncoordinated manner. It is possible to adjust the length of the control sticks of the transmitter and on the accident flight he recalled that they were at their shortest setting. He was used to flying with much longer sticks where the distance from neutral to full deflection would have been further. It is his opinion this is why he applied full throttle instead of an intermediate amount of throttle to correct the descent.

The RP switched to LOITER mode and returned the sticks to the neutral position to allow the automation to regain control. However, the aircraft was too far out of the flight envelope for the automation to recover and was travelling towards the RP and GCS operator, so the RP closed the throttle and allowed the aircraft to impact the field.

Operator actions

An internal review by the operator after this event highlighted that a larger geofence could have been set as there were no airspace restrictions at the training site and their OA allowed them to operate with an operational volume of 120 m high by 500 m radius.

The review also considered the appropriateness of using STAB mode. The aircraft manufacturer did not think it should be used as it is a reversionary mode which would only be used in the event of multiple sensor failures. The operator concluded that they would no longer use it and flying should be conducted in either ALT HOLD or LOITER mode. In addition, the review concluded that the use of standard phraseology is to be adopted to accurately relay information between the RP and the GCS Operator. In conjunction with enabling the audio alerts from the GCS, which can be heard over the two-way radio, it was felt that this would prevent situations from occurring, such as a geofence breach.

Operating Safety Case

The investigation reviewed the OSC documents, and several findings were identified relating to operating with a geofence which may have contributed to the accident.

Definition of a geofence

The maximum operational volume allowed is defined in the OA as 400 ft above the surface and 500 m from the RP. Volume 1 section 25.5 Geofence defines the SAV model that RPs and mission commanders '*must understand*'. The '*Power On and Safety Checks*' checklist states that the geofence is to be ENABLED and '*set appropriately*'. The geofence for the accident flight was 40 m (131 ft) by 300 m and was a standard training envelope but neither the RP nor the GCS operator recalled a discussion whether this size was appropriate. The height of the geofence was a causal factor in the accident.

Geofence procedures

It was considered by the operator that all the RPs were experienced and therefore there was no requirement to detail the actions to be taken in the event of a geofence breach. The geofence diagram in the OSC states that when the aircraft crosses from the flight geography volume to the contingency volume there are '*Contingency procedures'* and *'Emergency procedures'* when the aircraft leaves the operational volume. The investigation could not find either contingency or emergency procedures for either case.

The practise of cancelling the RTL in the event of the geofence breach was normalised behaviour to save time. The RP was aware that he breached the top of the geofence and felt comfortable cycling the flight mode switch on the handset to restore the aircraft to the manual flight mode. This action was carried out spontaneously without conscious awareness of the throttle setting and therefore the aircraft entered the manual mode with the throttle almost fully closed which resulted in the loss of control. Following this accident the operator will train RPs, when cancelling an automated flight mode, to revert to LOITER mode thereby excluding the controller throttle setting.

Training

Recurrent flight training relied only on '*self-identified*' weaknesses to be practiced as opposed to a structured training plan which would have defined regular practise of normal and non-normal procedures. There was no requirement for an objective assessment of flying skills and the identification of any specific skills that needed practise. The repetition of non-normal procedures in a training environment can result in a more consistent application of defined procedures in times of high workload. This informality may have led to the RP being comfortable with cancelling the RTL and continuing with the flight after the breach rather than to follow the OSC which stated that "emergency action" should be taken.

The size of the geofence used for the accident flight was considered a "standard training geofence". It was not clear to the investigation whether that was applicable to the recurrent training of the operators RPs or student RPs being trained by the operator. Had the height of the geofence been set higher the initiating event would not have occurred. The lack of a definition of what is an '*appropriate'* geofence contributed to this. The investigation also noted that the 300 m radius geofence encompassed a railway line despite the OSC stating that flights should not come with 25 m of the railway line. The operator relied on the RP to ensure overflights did not occur, but the OSC stated that a '*Geofence will be used to maintain the aircraft within designated airspace*'.

Use of geofences as a risk mitigation

The use of a geofence (followed by an automated RTL) was the mitigation identified in the OSC to reduce the impact of several risks to as low as reasonably practicable. These risks are applicable to all flights conducted under the OA. For the mitigation to be effective the geofence needs to be adequately defined so that when the automation takes control it is sufficient to reduce the impact[3] of the risk. As part of the OA review process the granting authority should ensure that the OSC contains sufficient detail regarding the definition of the safety feature and the procedures by which it is implemented. Without these, the safety feature cannot be effective to mitigate the risk.

Therefore, the following Safety Recommendation is made:

Safety Recommendation 2024-106

It is recommended that the UK Civil Aviation Authority, when granting Operational Authorisations for Unmanned Aircraft Systems in the specific category, ensure that any safety feature that is used to mitigate risks, is adequately defined in the Operational Safety Case and includes the necessary operational procedures.

The contract between the prime contractor and operator has now been completed so it is not expected that any update to the OSC for this operation will be made.

Conclusion

Control was lost of an unmanned aircraft during a training flight following a geofence breach. The height of the geofence was not evaluated prior to the flight to determine its appropriateness. The lack of a structured training programme and the normalisation of cancelling the RTL by cycling the flight mode switch resulted in the aircraft leaving an automated mode with low throttle applied. This throttle setting was insufficient to maintain controlled flight and the subsequent actions to regain control were unsuccessful.

The OSC, on which the CAA granted an authorisation for Specific Category flying, was missing definitions and procedures specific to the use of geofences and actions to be taken in the event of a breach. These omissions have a further effect as the use of a geofence is widely used as a mitigation for many other operational risks.

Footnote

3 The use of a geofence will mitigate the impact of a risk and not the probability of occurrence.

Appendix – Risk assessments using a Geofence to mitigate the impact

Hazard	Mitigation	Argument	Evidence
FrSky Transmitter, Receiver or Link Failure	During Operations: • Ground power options • Geofence • Automation • Visual and audio warnings • Spare battery	During operations: Geofence will be used to maintain the aircraft within designated airspace.	Volume 1 25.5 - Geofence
GCS Failure and/or Link Degradation	Design: • Ardupilot native geofence • SMC logic • FrSky pathway • Remains in safe airspace • Robust Change Management process	Technical Mitigation: The UAS is programmed with an Ardupilot circular Geofence in which it must remain. If the aircraft attempts to exit the Geofence, either horizontally or vertically, the system will automatically limit the flight path.	Volume 1 25.5 - Geofence
GNSS Degradation	Design: • GNSS redundancy • Still airworthy without GNSS • Regain GNSS data, geofence • Robust Change Management process	Technical Mitigation: If the aircraft departs VLOS and regains GPS, the UAS is programmed with a Geofence. If the UAS attempts to exit the Geofence either horizontally or vertically, the system will automatically intervene.	Volume 1 24.1.3 - Geofence [sic – does not exist]
Flyaway - Air	Unmitigated failure: • Geofence failure During Operations: • After take-off checks • Wind direction noted • Telemetry noted for faults • Geofence • VLOS	During operations: Geofence will be used to maintain the aircraft within designated airspace.	Volume 1 25.5 - Geofence

Hazard	Mitigation	Argument	Evidence
Flyaway - Ground	Unmitigated failure: • Geofence failure Technical malfunction: • Software error During Operations: • After take-off checks • Wind direction noted • Telemetry noted for faults • Geofence • VLOS	During operations: Geofence will be used to maintain the aircraft within designated airspace.	Volume 1 25.5 - Geofence Volume 2 1.9 - Pos, Nav & Guidance 1.13 - Safety Systems
Small Mission Computer (SMC) negatively influences the functionality of RPAS flight control	Design: • Comprehensive Change Management process to document configuration control activity • Geofence function integrated and enabled • RTH function integrated and enabled • Software changes are evidenced and practiced in simulation and live flying on proxy aircraft prior to live flight on T150	Technical Mitigation: Geofence is enabled on T150, and SMC is unable to over-ride.	Volume 1 1.13 - Safety Systems Volume 2 25.5 - Geofence

Published: 5 September 2024.