SERIOUS INCIDENT

Aircraft Type and Registration:	Tekever AR5 Evolution Mk 2, G-TEKV
No & Type of Engines:	2 3W 2-stroke piston engines
Year of Manufacture:	2019 (Serial no: E505)
Date & Time (UTC):	29 December 2020 at 1446 hrs
Location:	Lydd Airport, Kent
Type of Flight:	Commercial operations (UAS)
Persons on Board:	Crew - None Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	None
Commander's Licence:	Other
Commander's Age:	33 years
Commander's Flying Experience:	1,514 hours (of which 665 were on type) Last 90 days - 105 hours Last 28 days - 34 hours
Information Source:	Field Investigation

Synopsis

While orbiting south of the runway in preparation for landing, both the unmanned aircraft's engines shut down unexpectedly. The External Pilot on the ground, who was visual with the aircraft, took control and landed it without further incident. The dual engine shutdown was likely to have been caused by an on-aircraft data error. Various safety actions, including improvements to the aircraft's hardware and software, and the Ground Control Station software, have been taken to reduce the risk of a reoccurrence.

History of the flight

The unmanned aircraft, G-TEKV, was returning to Lydd Airport from a flight over the English Channel. Flight operations were conducted from a Ground Control Station (GCS) where the crew control the aircraft from takeoff to landing and operate the payload to fulfil the mission objectives. The GCS contained two stations, the flight GCS (fGCS) and the mission GCS (mGCS). The fGCS focused on all aspects of the control of the aircraft platform, whereas the mGCS focused on the mission goals and operation of the payload.

The GCS was manned by the Mission Commander (MC), the oncoming Internal Pilot (IP), the off-going IP, and the Payload Operator (PO). An External Pilot (EP)[1] and a Maintenance Technician (MT) were positioned at the side of the runway abeam the intended touchdown position for the aircraft and both could communicate with the IP through air band radios.

Footnote

[1] The EP may also be referred to as a Safety Pilot (SP).

While the aircraft was orbiting off the coast prior to transiting back to the airfield, the two IPs conducted a handover; the off-going IP remained to act as a second pilot to assist with the conduct of the remainder of the flight. Meanwhile the EP advised that the wind favoured a landing on Runway 03 with a light crosswind.

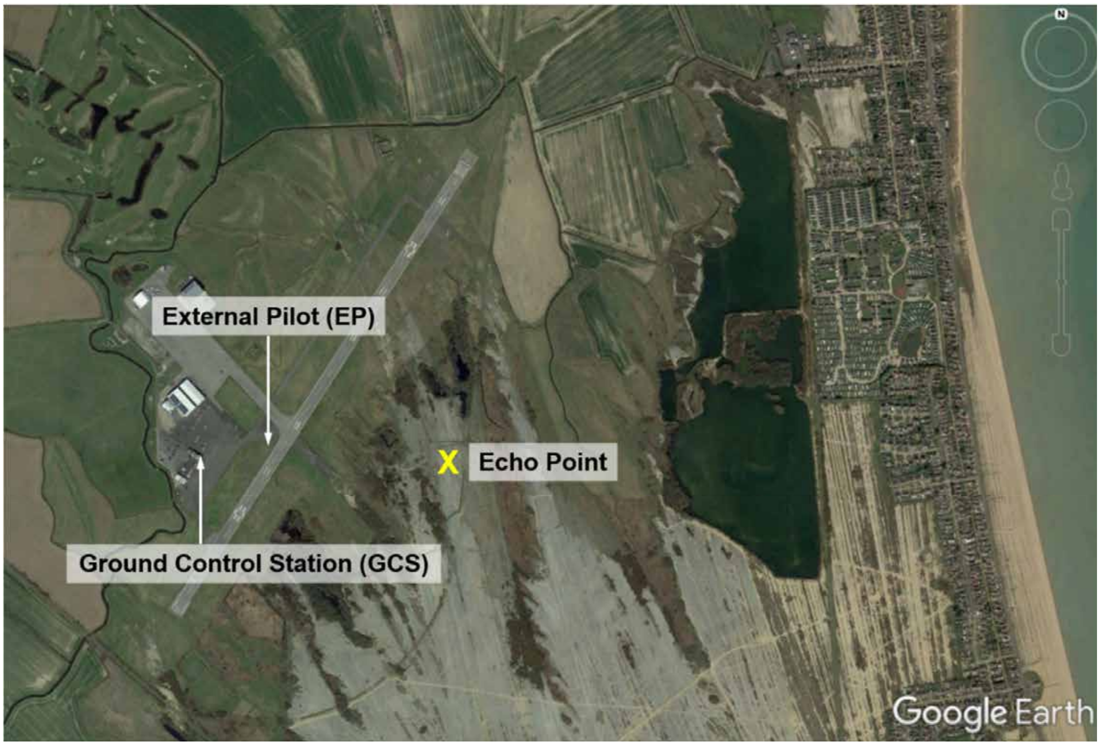

Figure 1

Lydd Airport and Echo Point

The aircraft transited towards the airfield at 700 ft amsl to remain clear of the cloud and icing. On reaching Echo Point, overhead the airfield (Figure 1), the aircraft entered an orbit while the IP, assisted by the off-going IP, proceeded to load the mission waypoints for a landing on Runway 03. Meanwhile, the EP reported to the GCS that he could hear the aircraft but was not visual with it. The MC instructed the IP to descend the aircraft to 600 ft at which point the EP confirmed that the aircraft was visual and clear of cloud.

With the aircraft established at 600 ft in the orbit at Echo Point and the mission points uploaded, the IP informed the EP that the aircraft was set up for the landing. The EP acknowledged and the IP switched the aircraft to ROUTE mode[2] to proceed with the approach and landing on Runway 03. After the aircraft completed two more orbits, the crew in the GCS noticed that it did not appear to leave the orbit at the expected point to establish itself downwind.

As the aircraft flew the final orbit, the EP outside was expecting the call 'downwind' from the GCS team. He noticed the aircraft level its wings, as expected when departing the orbit,

Footnote

2 This is an automatic mode where the aircraft follows a specified route defined of sequential waypoints defined by location and altitude.

but observed the nose drop more than normal. At this point the EP became aware that he was not able to hear the aircraft's engines. He operated the throttles and confirmed that there was no engine response. The EP switched to FLY-BY-WIRE (FBW)[3] mode, took control of the aircraft, confirmed control response, and instructed the MT to inform the GCS about the complete loss of engine power.

While this was happening, the flight team in the GCS was first alerted that something was amiss when they observed the aircraft fly on a westerly heading towards the runway and not along the expected track to establish itself downwind parallel to the runway. None of the team reported seeing or hearing any alarms or warnings. The MC noticed that the height of the aircraft appeared low, and the off-going IP then noticed that the displayed parameters for both engines indicated zero rpm.

The MC, unaware that the EP had already taken control of the aircraft, gave instruction to the IP to advise the EP to do so and went outside the GCS to observe the aircraft. The MT advised the IP that the EP had already taken control and so, from that point on, the IP provided speed information to the EP until the aircraft had landed.

The EP assessed the conditions and positioned the aircraft on final approach; it landed without further incident.

June 2020 event

This event followed a related one that occurred in June 2020 where, during an integration ground test of equipment onto a new AR5 aircraft at the manufacturing and development site in Portugal, both engines shut down, uncommanded by either the GCS or the EP.

Lydd Airport

Lydd Airport has an elevation of 13 ft amsl and is situated about 1 nm inland from the south coast. At the time of this event the airfield was closed, and ATC was not manned. The operator had authorisation to operate the aircraft from the airfield when it was closed.

Personnel

Crewing

The MC leads the team in the execution of the flight and its mission.

The IP is the fGCS operator and is responsible for the control and navigation of the aircraft.

The IP communicates with ATC, when available, and other aircraft to ensure deconfliction. The PO is the mission GCS (mGCS) operator and is responsible for the management of the payload.

Footnote

[3] The EP controls the aircraft's roll and pitch angles and throttle (using his radio controller) and the aircraft is stabilized within control limits. The rudder is either controlled manually or automatically with aileron movement. In this mode of operation, the IP is required to constantly update the EP with speed information.

The MC, IP and PO are located in the GCS for the mission.

The EP is responsible for ground manoeuvring, takeoffs and landings, and provides redundancy while the aircraft remains within Radio Line of Sight (RLOS) of him in the event of signal loss between the aircraft and the GCS. For departure and arrival, the EP stands at the side of the runway abeam the intended departure or landing point. The EP has an air band radio to listen to the information passed by the IP in the GCS but relies on the MT to transmit any information back to the GCS.

The MT is responsible for ensuring the aircraft is serviceable and operational. During takeoffs and landings, the MT accompanies the EP to act as a communications relay between the EP and the IP in the GCS.

Training and experience

All the pilots satisfied the qualification and competency requirements specified in CAP 722[4]. Each of the crew members had successfully completed the operator's own competency training programme for the aircraft in their specific roles. The MC, IP and PO all had previous experience operating UAS and were trained for both the IP and PO roles. The EP had satisfied the required competency training for his role and it was noted that he had extensive experience in flying radio-controlled models, including 40% scale aircraft.

Recorded information

Recorded data was available from both the aircraft and GCS. Flight data was stored in a log file on the aircraft which included: flight control data (such as received control commands and control surface deflections); GPS-sourced data; engine data, aircraft attitudes and aircraft modes (such as 'Fly by wire'); and messages (such as 'Ignition OFF'). The aircraft was also fitted with cameras, but these were not active during the event. The GCS recorded data into three log files. One of these included telemetry data from the aircraft that was GPS timestamped. The GCS had no facility to record alarms and warning triggers, either in a log file, visually or audibly.

Figure 2 shows the flight track of the aircraft from the last of six orbits around Echo Point through to the landing. The aircraft came into radio range of the EP's controller at 1437:30 hrs near Echo Point and commenced the orbits at about 750 ft. From the flight log it was determined that during the last orbit an engine 'Ignition OFF' command was detected by the autopilot after which the engines shut down. The EP started making roll control inputs to level the wings 17 seconds after the 'Ignition OFF' command (overriding the autopilot) before switching to FBW mode 11 seconds later.

Footnote

[4] CAA, CAP 722, 'Unmanned Aircraft System Operations in UK Airspace – Guidance' 7th Edition, amendment 2019/03, 4 September 2019.

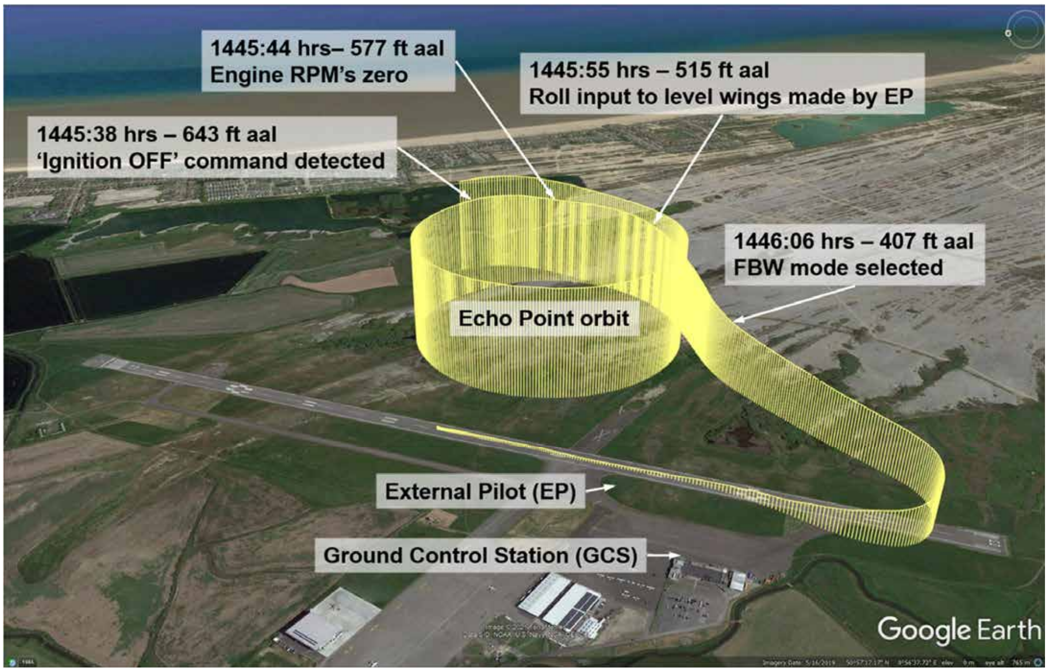

Figure 2
Aircraft flight path during the event

Aircraft information

System description

The Tekever AR5 Evolution UAS (AR5) consists of a manned GCS and an unmanned aircraft (Figure 3). G-TEKV was manufactured and operated by the same organisation and, for this report, is referred to as the operator.

Command and control of the aircraft is achieved through the use of RLOS and Beyond Radio Line of Sight (BRLOS) communication data links. The system has six data links in total, five of which carry primary and secondary RLOS and BRLOS capability. The sixth link is a radio link used for control of the aircraft by the EP. The RLOS control system operates in one frequency band and has a maximum range of 3 km, the backup RLOS system operates at a different frequency and has a range of 4 km. For BRLOS the system uses 4G and Satcom channels to maintain communication with the aircraft. In the event of a loss of the link, the aircraft can remain in a holding pattern to try and re-establish communications. If, after a defined period, the aircraft has not established communications, it can return home and perform an automatic landing.

Figure 3
Tekever AR5 Evolution

Aircraft description

The aircraft has a maximum takeoff mass of 180 kg, a wingspan of 7.29 m, a length of 4.03 m and a fuel tank capacity of 60 litres. It is powered by two 170 cc two-stroke boxer engines manufactured by 3W which generate 9.43 kW at 5,600 rpm. An external electrical engine starter is manually connected to each engine before start-up. Once the engines are running the starters are disconnected. The AR5 does not possess a built-in engine start capability. The aircraft fuel system consists of one central tank in the fuselage and two electric fuel pumps.

The avionics systems can be considered as falling into two main categories. Firstly, all the critical systems that affect safe control and navigation of the aircraft. These comprise the Flight Management System (FMS), Autopilot, Actuator Control Electronics (ACE), Electronic Fuel Injection (EFI) and the sensors and actuators to control the flying control surfaces. Secondly, the avionics and systems that enable exploitation of the aircraft's mission systems. These include video processing and thermal imaging cameras.

In normal flight conditions the aircraft is controlled via the RLOS and BRLOS communication channel from the GCS. However, in an emergency the EP can take direct control of the aircraft via a separate controller with its own radio link. Although there is only one transmitter (used by the EP), at the time of the event the AR5 had a dual receiver system which provided redundancy should one of the receivers fail. The dual receiver system also marginally extended the range at which the EP could control the aircraft. The outputs from the dual receivers were routed through a multiplexer which merged the signals and passed them via the ACE to the Autopilot (Figure 4). When out of range of the EP's controller, receivers are programmed to send a signal down one of the control channels to the autopilot. The autopilot then ignores all the other control channel signals until a receiver detects that the aircraft is back in range.

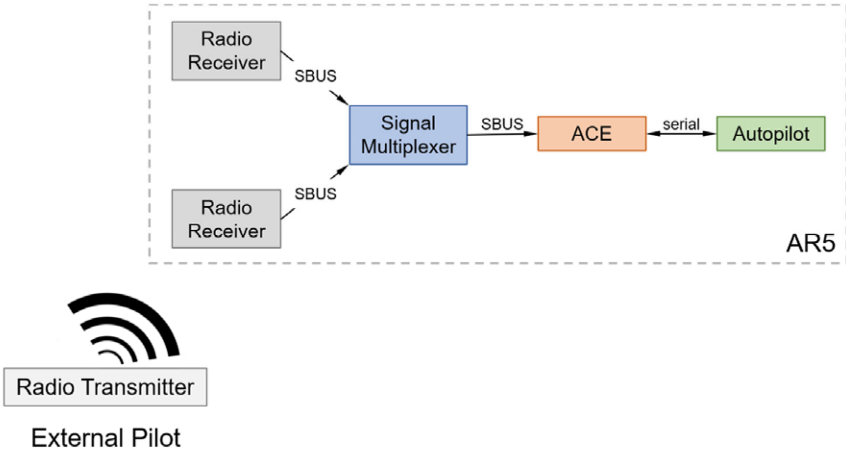

Figure 4
EP control path

Generator power unit (GPU)

The GPU is responsible for the management of the aircraft's electrical power systems, swapping from generator energy to batteries, charging batteries and managing external power sources. Within the GPU, switching regulators were used and the circuitry design followed the recommendations of the regulators' manufacturer. The regulators were certified to meet IPC 9592A, Category 2, Class II.[5]

EP radio link

The EP radio link is used to control the aircraft's ailerons, elevator, throttles, rudder, flight modes and the ignition switch. The autopilot receives command signals via the serial data bus from the multiplexer at a rate of 50 Hz but are only recorded in the flight log at 10 Hz (every fifth value received by the autopilot).

Each of the channel data on the serial data bus was in the form of an 11-bit value (0 to 2,047) for use by the autopilot. For the ignition switch channel, the 'Ignition ON' command was made by sending a pre-defined non-zero value, and the 'Ignition OFF' command by sending a value which is larger than a set threshold. Only one instance of a value exceeding the set threshold was required (of the 50 per second sent) to command 'Ignition OFF' and cut both engines. As such, a single bit error would be sufficient to modify the 'Ignition ON' signal value so that it exceeded the 'Ignition OFF' threshold.[6] Bit errors on the control surface channels, if infrequent, would have little noticeable effect as the control surfaces would not be able to react quickly enough before being commanded back to a 'good' value 0.02 seconds later.

Footnote

[5] IPC-9592A specifies the requirements for design, qualification testing, conformance testing and manufacturing quality/reliability processes of power conversion devices for the computer and telecommunications industries. Category 2 devices are board-mounted dc to dc convertors.

[6] For bit errors in the SBUS data stream to modify the 11-bit default value so that it exceeded the threshold, two combinations existed for a single-bit change, 15 combinations for a two-bit change, 56 for a three-bit change etc. of the 2,048 combinations of an 11-bit word. The highest number (but least likely) of bit-error combinations was 290 for changes to six bits.

GCS stations and displays

General

The fGCS consisted of a dual screen display, of which the primary screen displayed the Mission Station (MiSt) screen (Figure 5). The mGCS consisted of a three-screen display, one of which mirrored the MiSt display.

Figure 5

fGCS Primary display – MiSt screen

Flight Information Bar

The flight information bar is situated on the left of the MiSt screen. A pictorial display of an artificial horizon with speed, heading and altitude information is displayed at the bottom. In the middle of the bar, the signal integrity for each of the communication links is displayed through icons which are coloured according to a traffic light system. Above this, aircraft parameters are displayed and include information on the signals, battery levels, and engine parameters (which include engine rpm and throttle status for each engine). An enlarged view of that part of the flight information bar is shown in Figure 6. None of the aircraft parameters were colour coded according to status.

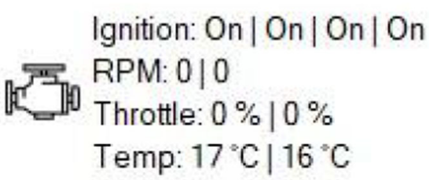

Figure 6

Flight Information Bar – Engine Parameters

Notifications and warnings

The conditions to trigger alerts and warnings could be set and enabled or disabled individually and were specific to the fGCS and mGCS stations. The conditions for engine alerts, including the LOW ENGINE RPM warnings were set on the fGCS station. An audible alert could be either enabled or disabled but applied to all warnings and alerts and could not be configured individually. There was also a configurable snooze function, which allowed an alert to be made temporarily inactive for a specified period of time.

The notification toolbar was situated in the bottom right corner of the screen and displayed any new event notifications, alerts or warnings to the IP. A new alert or warning was brought to the attention of the IP through an ALERTS/WARNING button at the bottom right of the screen which flashed red if a new warning had been activated.

By clicking the ALERTS/WARNING button on the notification toolbar, the IP could bring up a dialogue box with more detailed information on the warning or alert which allowed the IP to choose to either SNOOZE the alarm, IGNORE it, or LOCATE it. Once an action had been selected the ALERTS/WARNING button would turn black with white writing.

Organisational information

Regulation

At the time of the event, the aircraft was operating under the ANO (2016); the CAA had granted an Exemption for BVLOS operations. The original authorisations were granted under CAP 722 edition 6, but at the time of the event edition 7 was extant and stated:

> *'Operators of unmanned aircraft over 20 kg are required to apply for an exemption from the CAA. Any commercial operations aspects will also be covered within this exemption. The application must include a safety case including a risk assessment which demonstrates that the operation can be conducted in a safe manner.'*

The operator had provided an Operational Safety Case (OSC) to support its application to the CAA for an Exemption and, since that time, had updated it where appropriate.

Double Engine Failure

Volume 2 of the OSC outlined the emergency procedures in the event of a double engine failure on takeoff or en route; the routing to and from the airfield was designed to reduce the subsequent risk to third parties or property. The procedures included the designation, prior to departure, of emergency landing locations in case of loss of communications or propulsion, as well as the use of an External Pilot as a safety pilot.

Volume 3 of the OSC outlined the risk assessment. It identified three scenarios of relevance to this event together with measures to control the risk (Table 1).

Scenario	Extant Control Measures
A9 – SP [EP] *takes control of UAV* [Unmanned Aerial Vehicle] *with degraded performance*	1. Only qualified crew and in good health conditions operate Tekever AR5 Evolution 2. Ensure constant communications among crew members during the take-off/landing manoeuvres 3. IP is aware of degraded performance using the fGCS instruments 4. IP will inform EP about degraded performance
O2 – Non-EMI [Electromagnetic Interference] *related Double engine failure*	1. UAV maintenance is done by qualified crew and in good health conditions. Maintenance schedules reduce the risk of engine failure 2. IP monitors engine readings during the flight to detect potential problems 3. The UAV will attempt to land in a pre-planned landing area 4. The crew can use Flight termination system (FTS) to prevent further flight
O15 – Erroneous control actions by the autopilot	*1. UAV maintenance is done by qualified crew and in good health conditions to operate Tekever AR5 Evolution* *2. IP will detect erroneous actions by autopilot and perform the corrections needed* *3. FTS available* *4. Operating in restricted airspace within safety areas'*

Table 1

OSC risk assessment scenarios of relevance to the event

CAP 722 and airworthiness standards

Section 4 of CAP 722 (Edition 6) titled '*Certification & Airworthiness*' contained guidance on certification and the suggested approach for aircraft which do not require certification to formal standards. For this operation, the CAA used the OSC process, where applications would be scrutinised in a proportionate way to the risk its design and usage posed to the general public and property and, where there was a lack of demonstrable airworthiness, risks could be mitigated by operational limitations.

Appendix C of CAP 722 provided a template and guidance on how to complete an OSC. Volume 2, Section 1.1 '*Details of design and manufacturing organisation(s) and any recognised standards to which the equipment has been designed, built and tested*' stated that:

> *'Details of any standards that may or may not be aviation related and may add to the safety argument. Where known this must include test and evaluation evidence.'*

In Edition 7 of CAP 722, the following text was added to this section:

> *'Provide details of any recognised standards to which equipment relevant to the application has been designed, built and tested, for example, aeronautical standards such as EUROCAE and RTCA, or product standards such as ISO, ASTM, STANAG and BSI.'*

The OSC for this operation, developed under Edition 6 of Cap 722, did not contain details of any standards used. However, the operator advised that aircraft had been designed and built using STANAG 4703[7] as guidance, along with '*industry best practice*' but was '*not fully compliant to the standards.*' It also advised that software is designed using DO-178B[8] as guidance during the development process to '*ensure that there were no catastrophic errors.*' No formal testing against any of these standards was made, nor was any required for the Operational Authorisation.

In January 2021, the operator published internal document '*EMC* [Electromagnetic Compatibility] *Integration Considerations*' which detailed '*the procedures and best practices*' to be used by the operator '*to ensure that the integration of new equipment maintains the baseline EMC values*.'

The OSC contained information on how modifications were embodied and how configuration control was maintained. It did not, however, describe the process for developing the modification, but this was later clarified in the operator's document TAS-CMN-QAP-008_00 *Development Procedures in Electronics, Version 1* which was issued on 11 February 2021.

Operator's investigation of June 2020 event

Following the double engine shutdown event on the ground in Portugal in June 2020, the operator analysed the recorded data available and determined that, although the autopilot had received an 'Ignition OFF' command, the command had not been sent from either the GCS or EP.

After further testing, the operator identified erroneous values, in the form of bit errors, within the data passed from the multiplexer via the ACE to the autopilot (Figure 7) and began an investigation to understand how and where these signal errors were being introduced.

Footnote

[7] STANAG 4703 – Allied Engineering Publication AEP-83 '*Light Unmanned Aircraft Systems Airworthiness Requirements*' is a set of technical airworthiness requirements intended for the airworthiness certification of fixed-wing light military UAS with a maximum takeoff weight not greater than 150 kg that intend to regularly operate in non-segregated airspace over all population densities.

[8] DO-178B – Software Considerations in Airborne Systems and Equipment Certification – is a guideline dealing with the safety of safety-critical software used in airborne systems. The Software Level, ranging from Catastrophic (failure may cause a crash) to No Effect (failure has no impact of safety) is determined by examining the effects of a failure condition in the system.

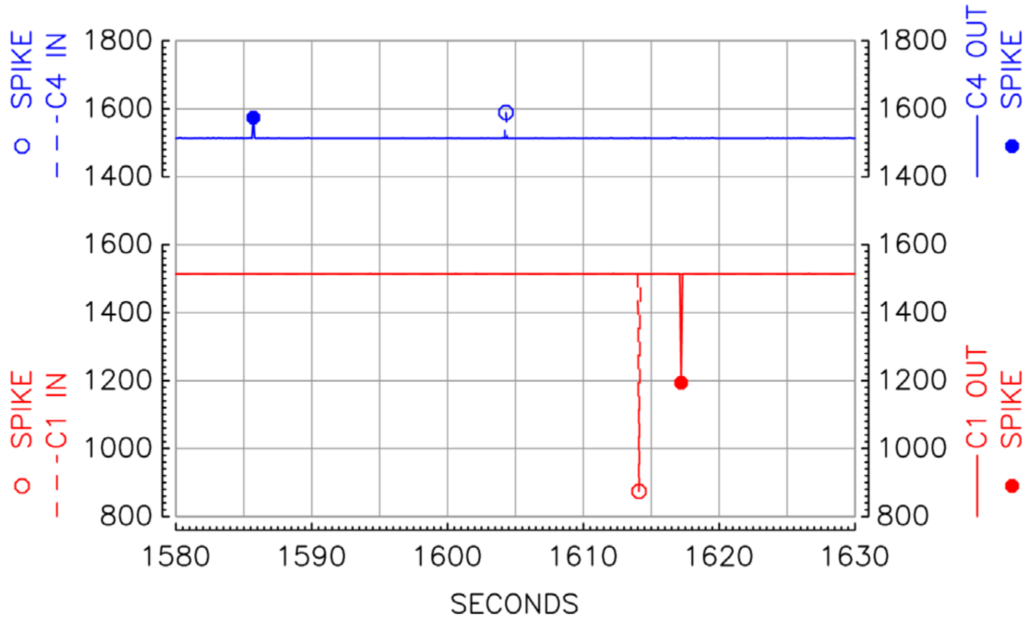

Figure 7

Data from the aircraft log file showing spikes on the control channels in and out of the autopilot for Aileron (C1) and Rudder (C4) for the June 2020 event

The operator's investigation followed several lines of inquiry:

1. ***EP radio link system robustness*** – since it appeared that there were wrong values being sent to the autopilot system.
2. ***Source of noise*** – since it appeared that higher system current loads increased the probability of the event happening.
3. ***Autopilot system*** – study the possibility of the autopilot incorrectly interpreting the control inputs and why the data logged for the ignition switch control contained no erroneous values.

The operator concluded that:

- The event could be replicated only if the multiplexer was in the system and that noise was detected on the output signal from the multiplexer.
- The noise level increased when the current loading from the aircraft's electrical systems increased implying that the GPU was the source of the electrical noise.
- The autopilot recorded the 50 Hz signal data at a rate of 10 Hz (to limit the quantity of data recorded) so some erroneous values might not be logged.
- Checking for a continuous 'Ignition OFF' command over a defined period of time (rather than a single value) would reduce the likelihood of the engines being shut down due to transient erroneous commands.

As a result of the operator's investigation into the June 2020 event the following safety actions were taken:

1. A new SBUS multiplexer hardware revision was released in June 2020 that fine-tuned the internal PCB design and some components to minimise the impact of external interference. It was noted that it was '*not fully protected against noise*'; however, the inadvertent engine shutdown event could not be reproduced during tests. This revision was embodied on the entire AR5 fleet, including G-TEKV which was modified in June 2020.

2. The GPU was redesigned to reduce Electromagnetic Interference (EMI) emissions. The GPU redesign was based on the standards of STANAG 4703, and tests were performed to comply with CISPR25 – Class 1.[9] This work was completed in the second quarter of 2021 and the new GPUs are being installed on new build aircraft and on those returned to the factory for maintenance.

The operator also recommended that the autopilot firmware be updated as soon as possible with a change to the detection of an 'Ignition OFF' command from a single instance to a requirement to have 10 consecutive valid commands. This change would prevent single erroneous 'Ignition OFF' commands from shutting down both engines. However, the operator decided that this was '*not a critical update'* given the apparent effectiveness of the multiplexer redesign. As a consequence, the firmware update was only applied to aircraft returned to the factory, or to new build aircraft. G-TEKV was built prior to June 2020, had not been returned to the factory since that date, and so did not have this firmware update embodied.

Following the serious incident in December 2020, the operator has now embodied this autopilot firmware update on the entire AR5 fleet of aircraft. It has also disconnected one of the EP channel radio receivers and bypassed the multiplexer completely. The operator noted that this decreased the radio range but '*continues to be in the distance needed for safe operation as described in the OSC*'. The operator also introduced an additional procedural control measure to disable the 'Ignition OFF' command unless the aircraft was within 500 m of the EP.

The operator reviewed the implementation of warnings and alerts to users of the GCS. The review noted that alert thresholds could be changed by users but that '*the warnings offer a high level of verbosity'* and that *'multiple warnings can be triggered when in a 'normal' state'*. It identified that this saturation of warnings could result in an alert or warning being made inactive by users to remove the distraction or that warnings risked being ignored.

Footnote

[9] Comité International Spécial des Perturbations Radioélectriques (CISPR) sets standards for controlling electromagnetic interference in electrical and electronic devices. CISPR25 details limits and procedures for the measurement of on-board radio disturbances in the range of 150 kHz to 2500 MHz. The standard applies to any electronic/electrical component intended for use in vehicles as well as boats powered by internal combustion engines, and devices also powered by internal combustion engines. Class 1 is the least stringent of the five classes within the standard.

The review recommended the implementation of a revised warning system with a notification/ warning message bar which would identify the alert without user action or intervention, and which would ensure that the information remained visible. In addition, the corresponding parameter on the flight information bar would be highlighted in red. From April 2021, the operator started to implement the revised system status reporting within the GCS software. This includes two alert levels (caution and warning) and a revised flight information bar with parameters colour coded according to status (an extract is shown in Figure 8).

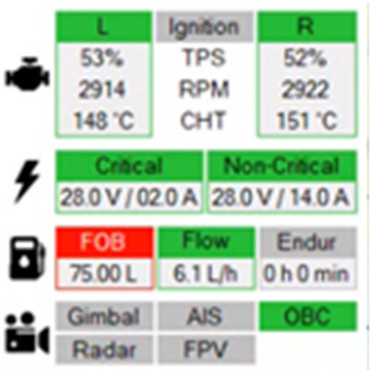

Figure 8
Revised flight information bar extract

Analysis

The event

Whilst the aircraft was returning to the airfield to land, both engines shut down at the same time and there was no means to restart them in the air.

The event occurred over the airfield at a time when the EP was prepared and expecting to take over flight control from the GCS team for the landing. Although the cause of this event was such that it could only have occurred whilst the aircraft was in radio range of the EP, it was fortuitous that it happened at a time when he had good visibility of the aircraft. He saw that there was a problem, took control in accordance with the actions stipulated in the operator's OSC, and his training and experience enabled him to glide the aircraft to an otherwise uneventful 'dead stick' landing on the runway.

There was a short period during which the crew in the GCS were unaware of the aircraft's degraded performance. None of them saw or heard any warnings or alerts associated with the loss of engine power and only became aware of an issue when they observed the aircraft deviating from the planned trajectory because the EP had taken control. The GCS crew noticed the aircraft descend and this then drew their attention to the engine indications on the fGCS primary display. Following an internal review, the operator has implemented a revision to the system status reporting within the GCS software.

The reason for the simultaneous shut down of both engines was likely to be a spurious 'Ignition OFF' command generated on the aircraft's EP controlling link through corruption of data provided to the autopilot from two radio receivers via a multiplexer. The presence of a single erroneous command was sufficient to cause the simultaneous engine shutdowns. This data corruption most likely originated from electrical noise as a result of electromagnetic interference originating from the GPU, which affected the operation of the multiplexer. Data corruptions so caused were difficult to identify as only one out of five samples of data were recorded and the level of noise generated varied with the load on the aircraft's electrical system. Such data corruptions could only have an effect when the aircraft was within range of the EP's transmitter as the autopilot was programmed to ignore any commands received via this radio link at all other times.

Design, build and test standards

Following an earlier similar event in June 2020, the operator did identify and implement improvements to the multiplexer to make it more resistant to electromagnetic interference. Subsequent testing could not reproduce the issue and so the operator considered that the problem had been resolved and this improvement was embodied on all AR5 aircraft. However, believing that the multiplexer redesign had solved the problem, an associated update to the autopilot firmware to improve resilience to spurious commands (which included the agreed change to the 'Ignition OFF' logic in the autopilot software) was considered not to be critical. It was decided that existing aircraft would only be updated on their next return to the factory for maintenance. G-TEKV was equipped with the improved multiplexer but not the updated autopilot firmware at the time of the event in December 2020.

It is unclear exactly what EMC tests were carried out after the June 2020 event and if these were the same as those carried out during the development and testing phase of the aircraft. However, with the modified multiplexer installed, these tests did show that noise could still be detected on the control signals. The fact that the noise did not trigger an 'Ignition OFF' command during these tests and would have had negligible impact on the other control inputs to the autopilot, resulted in a false assumption that the issue had been resolved.

The standards to which the aircraft was built and tested to were not described in the OSC and, although the OSC template in CAP 722 had provision for this information, there was no requirement for it to be included.

Various aeronautical and transport standards were used as guides for the design and testing of the aircraft, representing best practice at the time. No formal testing against any of these standards was conducted so it is unknown if the aircraft design would have passed these. The OSC template referred to in later additions to CAP 722 now include examples of aeronautical standards that could be applied but there are still no requirements for these standards to be met. In March 2021, in a report of an accident to a Alauda Airspeeder Mk II UA[10], the AAIB made recommendations to the CAA and EASA to: '*adopt appropriate design, production, maintenance and reliability standards for all Unmanned Aircraft Systems with aircraft capable of imparting over 80 joules of energy*[11].' In response

Footnote

[10] AAIB Bulletin 03-2021.indd (publishing.service.gov.uk) [accessed 9 August 2021]

[11] 80 joules of kinetic energy (equivalent to a 1 kg mass falling to the ground from about 8 m) is the limit specified in EU Commission Implementing Regulation 2019/947 for UAs in the Open category that can be operated intentionally over 'uninvolved people'.

to these recommendations, both organisations have indicated the intent to develop, and adopt into regulation, such standards as are deemed appropriate and proportionate for the various types of UAS design and operation.

Conclusion

While the unmanned aircraft was orbiting south of the runway in preparation for landing, both engines were commanded to shut down due to a spurious 'Ignition OFF' signal being detected by the autopilot. It was likely to have been caused by electromagnetic interference from the aircraft's generator power unit corrupting some data on the radio channel used by the EP to control the aircraft. The EP on the ground, who was visual with the aircraft, took control and landed it without further incident.

This event followed a similar erroneous 'Ignition OFF' signal six months earlier during a ground test. As a result of the operator's investigation into the first event, design changes were made to the aircraft to limit the effect of interference, not all of which had been implemented by the time of the second event. Following this second event, a number of additional safety actions have been taken by the operator.

Safety actions

Since the June 2020 and December 2020 events, the operator has:

Redesigned the GPU to reduce emissions and is installing these on the AR5 aircraft fleet.

Changed the design of the radio command channel used by the EP and bypassed the multiplexer.

Embodied an autopilot firmware update on the AR5 fleet of aircraft so that 'Ignition OFF' must be asserted for 10 consecutive commands to trigger engine shutdown.

Introduced an additional procedural control measure to disable the 'Ignition OFF' command unless the aircraft is within 500 m of the EP.

Implemented a revision to the alerting system within the GCS software to improve its effectiveness.

Revised its internal documentation to include modification design and embodiment processes and to ensure that consideration is given to EMC for the integration of new equipment.

Published: 21 October 2021.