Serious Incident

Aircraft Type and Registration:	Ikarus C42 FB80 Bravo, G-CICF
No & Type of Engines:	1 Rotax 912-UL piston engine
Year of Manufacture:	2013 (Serial no: 1305-7260)
Date & Time (UTC):	8 December 2022 at 1150 hrs
Location:	Headcorn Aerodrome, Kent
Type of Flight:	Private
Persons on Board:	Crew – 1 Passengers – 1
Injuries:	Crew – None Passengers – None
Nature of Damage:	Aircraft main battery destroyed, and thermal damage to cockpit floor
Commander's Licence:	National Private Pilot's Licence
Commander's Age:	57 years
Commander's Flying Experience:	107 hours (of which 101 were on type) Last 90 days – 0 hours Last 28 days – 0 hours
Information Source:	AAIB Field Investigation

Synopsis

The aircraft's lithium-ion main battery caught fire shortly after takeoff, creating significant quantities of smoke and hazardous gases within the aircraft cabin that affected the ability of the pilot to safely control the aircraft. A passenger, sitting in the right seat, was able to open the cabin door in flight, which reduced the level of smoke in the cabin and the aircraft landed safely.

The investigation did not identify the cause of the battery fire. The location of the battery within the aircraft's cabin exposed the occupants to significant hazards when the battery caught fire, as the battery box did not contain the combustion products or heat from the fire. A similar airborne battery fire to the same aircraft type and lithium-ion battery type was found to have occurred in Germany, resulting in destruction of the aircraft.

One Safety Recommendation is made relating to reviewing the installation requirements of lithium-ion main batteries in cabin areas of Non-Part 21 aircraft, to minimise the effect to aircraft occupants following a battery fire.

History of the flight

The pilot was intending to make a short local flight to maintain flying currency. He was accompanied by an instructor, who was sitting in the right seat and was a passenger for the flight. The pre-flight check, engine start and pre-takeoff checks were normal.

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The aircraft took off from Runway 28 Left at Headcorn Aerodrome and climbed to an altitude of 1,300 ft before turning to the south once it had left the ATZ. Shortly after the southerly turn, both occupants observed smoke in the cabin, which the pilot later described as "very bad". He selected the battery master switch to OFF, however smoke continued to fill the cabin. The pilot positioned the aircraft for a downwind landing on the departure runway, whilst his passenger managed to open the upwards-opening cabin door, which he held a few inches ajar, allowing most of the smoke to be sucked outside the cabin.

The aircraft landed downwind and rolled to a stop. The pilot shut the engine down and both occupants then promptly left the aircraft. The airfield RFFS arrived at the aircraft and, having been briefed by the pilot that the main battery had caught fire, discharged two CO_2 extinguishers onto the battery, which was still burning (Figure 1). They then removed the burnt battery pack from the aircraft.

Figure 1

RFFS discharging a CO_2 extinguisher onto G-CICF's battery

Aircraft information

The Ikarus C42 is a two-seat high-wing microlight aircraft with a fixed tricycle landing gear. G-CICF is a factory-built example, operated on a Permit-to-Fly issued by the British Microlight Aircraft Association (BMAA). Whilst the majority of the UK C42 fleet operate on BMAA Permits-to-Fly, a number of kit-built C42s also operate on Permits-to-Fly issued by the Light Aircraft Association (LAA). The C42 is classified as a Non-Part 21 aircraft and is regulated in accordance with the UK Air Navigation Order[1].

Footnote

1 Additional information is contained in the *'Other information'* section of this report.

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Battery installation and charging system

G-CICF is equipped with a single main battery used for engine starting and power for the avionics, electric fuel pump, electric trim and aircraft lighting. The battery is secured in a battery box mounted on the main fuselage tube between the cabin seats, with the top of the battery projecting outwards, beneath the co-pilot's seat base. Whilst the battery box provides a mounting location for the battery, it is open at the top and there is no provision for containment or overboard venting of gases generated by the battery.

The battery is charged by an alternator and voltage rectifier-regulator when the engine is running. The battery charging circuit in G-CICF was not fitted with a separate over-voltage protection (OVP) device to limit the charging voltage supplied to the battery.

The aircraft was originally equipped with a 12 V sealed lead-acid battery, which had a mass of 2.7 kg. This was replaced in October 2016 with a new LiFePO4 lithium-ion battery[2] of slightly smaller external dimensions and a mass of 0.85 kg, providing a payload increase of 1.85 kg. The battery change was the subject of a standard BMAA Minor Modification (Technical Information Leaflet (TIL) 117). The modification required provision of a means for the pilot to isolate the battery from the charging circuit, which in G-CICF was met by the battery master switch. The completed modification paperwork also included confirmation that the aircraft had a voltmeter fitted to the instrument panel *'marked for overcharge condition'*. This analogue voltmeter (Figure 2), had a marked range of 8.0 to 16.0 V, with a green band between 12.0 and 14.0 V.

Figure 2

Voltmeter fitted to G-CICF, showing green band marking between 12.0 and 14.0 V

Footnote

2 Super B SB12V5200P-BC LiFePO4 battery, with a capacity of 60.7 Wh. LiFePO4 is a type of lithium-ion battery in which the cathode is composed of lithium iron phosphate.

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TIL 117 did not contain any requirement to fit an OVP to the battery charging circuit. The LiFePO4 battery installed in G-CICF had accumulated 1,338 hours in service since installation, with no problems experienced prior to the battery fire.

In May 2017, Comco Ikarus Gmbh issued Service Bulletin SB-42-020-2017[3] requiring an OVP to be fitted to Ikarus C42s equipped with lithium-ion main batteries. Comco Ikarus Gmbh, based in Germany, is the manufacturer of C42 aircraft and kits. Ikarus C42 aircraft are imported to the UK by a UK agent that holds a CAA BCAR A8-1 (A1) Primary Company approval[4]. This approval permits the holder to certify that an aircraft has been designed, manufactured, inspected and tested to show conformity with British Civil Airworthiness Requirements. Under this A8-1 approval, Comco Ikarus Gmbh is considered to be a sub-contractor supplier to the A8-1 holder.

It is a requirement of an A8-1 approval that the holder establishes a suitable monitoring system in order to provide information on problems or defects of a product supplied by the approval holder. This includes reviewing and acting upon any product safety-related data produced by a sub-contractor to the A8-1 holder. Despite this requirement, the A8-1 organisation did not assess the information contained in SB-42-020-2017 and therefore there was no requirement in place to fit an OVP to any UK-registered Ikarus C42 fitted with a lithium-ion battery, including G-CICF.

The A8-1 holder stated that as the lithium-ion battery installation in G-CICF was a BMAA modification, the aircraft owner had no obligation to share the information with them and they were unaware of the modification status of the aircraft. They further stated that, since taking on the A8-1 approval, they had not sold a C42 aircraft fitted with a lithium-ion battery and advise their customers to use sealed lead-acid batteries.

Battery description

The LiFePO4 battery fitted to G-CICF consisted of eight individual lithium-ion cells packaged within a plastic battery pack, with two terminal connectors on the top of the pack. The eight cells are electrically divided into two assemblies of four cells connected in series, with the two assemblies then connected in parallel. The nominal voltage of each cell is 3.3 V, giving a nominal battery pack voltage of 13.2 V. The battery manufacturer stated that the deep-discharge limit for the battery cells is 2.0 V, or 8.0 V for the battery pack, and that if the battery is discharged below this level it should be removed from service and discarded, due to the possibility of damage to the cells.

The battery was equipped with a voltage management system (VMS). The VMS controls the voltage level in each cell to ensure that the voltages across the cells are balanced, and that individual cell voltages do not exceed 3.65 V (14.6 V for the battery pack, which is the stated maximum charging voltage). The VMS does not provide any means of disconnecting

Footnote

3 www.comco-ikarus.de/wp-content/uploads/2019/11/2017_05_SB-42-020-2017-Start-Accus_EN.pdf [accessed February 2024].

4 CAA CAP583 BCAR Section A, Airworthiness Procedures where the CAA has Primary Responsibility for Type Approval of the Product, Issue 8 including amendment 1, 15 December 2017.

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the battery from an electrical load if the battery voltage falls below the deep-discharge limit of 8.0 V, or if the charging voltage exceeds the 14.6 V charging limit.

Literature provided by the battery manufacturer stated that no 'jump starting[5]' of the battery is permitted, due to the possibility of damage to the cells. If connected to an external battery charger, the charger must be of the CCCV[6] type as other types of charger, including those suitable for lead-acid batteries, may damage the battery cells.

The battery life was listed by the manufacturer as more than 1,000 charging cycles, where one charge cycle is defined as a period of use from fully charged, to fully discharged, and back to fully charged again. A single engine start is not sufficient to fully discharge a completely charged battery. No calendar life for the battery is specified by the manufacturer.

The investigation was unable to determine whether G-CICF's lithium-ion battery had been subjected to any use outside the manufacturer's specifications, such as jump starting, overcharging or excessive discharging. The manufacturer stated that it considered jump starting or excessive discharging as the most likely causes for the subsequent battery failure and thermal runaway.

Guidance for use and care of lithium-ion batteries

In June 2018 the BMAA published guidance on the installation, use and hazards associated with lithium-ion batteries in its Microlight Flyer magazine[7]. This article summarised the BMAA's modification requirements for installation of lithium-ion batteries, the risks associated with overcharging and the importance of using the correct type of battery charger.

Combustion products generated during a lithium-ion battery fire

Thermal runaway may occur within a lithium-ion battery pack when a short circuit develops in a cell, either due to internal damage to the cell caused by overcharging, over-discharging, physical shock, cell penetration, manufacturing faults, lithium dendrite formation[8] or by external overheating. Excessive heat within a cell can trigger an exothermic chemical reaction which produces additional heat and the release of gases. If the release of heat is sufficiently large, the ability of the battery cells and surrounding material to absorb the heating is overcome. The release of heat generation then becomes self-sustaining and the battery enters thermal runaway.

Footnote

5 'Jump starting' is a colloquial term used to describe the parallel connection of a discharged battery to a source of electrical power such as the battery from a running car, or an external jump starter battery pack. Cell damage may occur to a discharged lithium-ion battery when jump starting due to high current flow into the discharged cells.

6 Constant Current Constant Voltage (CCCV) is a battery charging cycle used for lithium-ion cells in which the cells are initially charged at a constant current. Once the cells are nearly fully charged, the charger changes to a constant voltage mode.

7 The charge of the lithium brigade, BMAA Microlight Flyer, June 2018.

8 Lithium dendrites are metallic tree-like structures that can form on the surface of the anode during charging cycles.

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Combustible gases released within the battery cells during thermal runaway increase in pressure until being released, either by a gas vent valve at the top of the cell, or by rupture of the cell. The release of the gas from the cell carries with it particles of the cell's organic solvent along with hydrogen, carbon monoxide, carbon dioxide, hydrogen fluoride and hydrogen chloride that form acid in contact with water vapour, hydrogen cyanide, hydrocarbons and toxic metallic particles of the battery cathode. If the combustible gases contact an ignition source, such as an electrical arc produced by a short circuit in a cell, a battery fire will occur.

Aircraft examination

The damage to the aircraft was limited to charring and scorching of the composite cabin floor around the battery box (Figure 3).

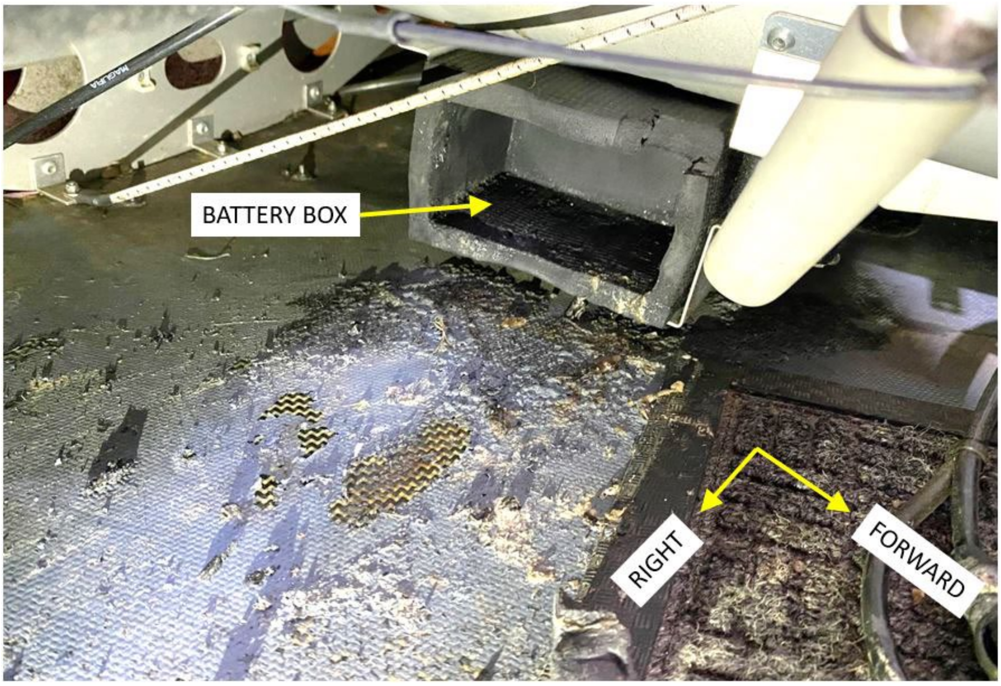

Figure 3

Damage to the cabin floor caused by the battery fire

The damaged parts from the battery were recovered and examined by the AAIB and the battery manufacturer (Figure 4).

The battery's external plastic case had melted and was penetrated between the battery terminals, indicating that the final stage of the thermal runaway was located close to this position. Seven of the cells had burst, due to excessive internal pressure, and one cell was intact and still retained a low voltage level of 0.16 V. The manufacturer stated that it was not possible to identify a cause for the battery thermal runaway due to the damaged state of the battery parts.

Figure 4

Damaged parts of the battery

Tests and research

A test flight was carried out on G-CICF using a datalogging voltmeter connected to the battery to measure the battery charging voltage in flight. The flight took place after G-CICF had been returned to service, fitted with a new sealed lead-acid battery, but with no alterations to the battery charging system. The test flight lasted 33 minutes in duration and included engine start and warmup, takeoff, a full power climb to an altitude of 3,000 ft, 10 minutes of cruising flight followed by a cruise descent and two circuits to full-stop landings. The voltage datalogger was set to record the battery voltage at four times per second (Figure 5).

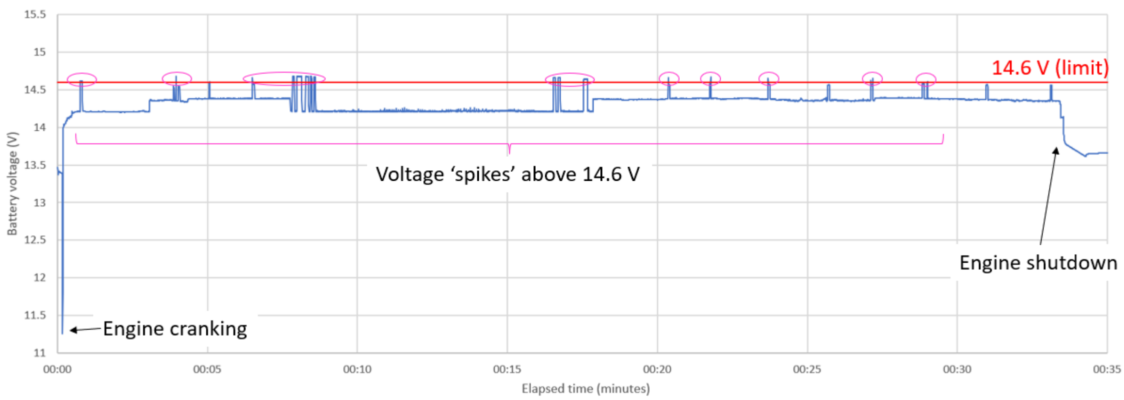

Figure 5

Battery voltage recorded during G-CICF test flight

The recorded data showed that the battery charging voltage varied during the flight, mostly between 14.2 and 14.4 V, but with numerous voltage ‘spikes’ up to 14.7 V, which was marginally in excess of the 14.6 V maximum permitted charging voltage specified by the battery manufacturer. The duration of the voltage ‘spikes’ was generally less than four seconds and were not noticeable on the analogue voltmeter fitted to the instrument panel.

The battery manufacturer stated that a lead-acid battery has a higher internal resistance than a lithium-ion battery, and therefore the voltage ‘spikes’ observed during the test flight were less likely to occur when a lithium-ion battery is installed.

Other information

Previous C42 battery fire event

The AAIB is aware of a second Ikarus C42 lithium-ion battery fire that occurred in Germany. This aircraft was fitted with the same model of battery as G-CICF and was also not equipped with an OVP device in the battery charging circuit. The aircraft was being flown solo when a battery fire occurred in flight. The pilot made a forced landing in a field and was not injured. The fire continued after the aircraft landed, eventually destroying the aircraft (Figure 6).

Figure 6

Ikarus C42 lithium-ion battery fire in Germany (image courtesy of manufacturer)

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BMAA lithium-ion battery Standard Minor Modification TIL 117

The BMAA TIL 117 Standard Minor Modification permits only certain approved LiFePO4 battery models to be installed, stating *'LiFePO4 chemistry is understood to be fundamentally reasonably safe, particularly concerning thermal runaway, which can be a significant problem with other lithium-ion chemistries'*. TIL 117 states that the approval basis for batteries in BMAA aircraft is BCAR Section S[9], S 1353:

> **Electrical Systems and Equipment**
>
> S 1353 **Storage battery design and installation**
>
> a) Each storage battery must be designed and installed as prescribed in this paragraph.
>
> b) No explosive or toxic gases emitted by any battery in normal operation, or as the result of any probable malfunction in the charging system or battery installation, may accumulate in hazardous quantities within the aeroplane.
>
> c) No corrosive fluids or gases that may escape from the battery may damage surrounding structures or adjacent essential equipment.

LiFePO4 batteries fitted must meet the UN DOT 38.3 certification which requires the battery manufacturer to demonstrate that the battery passes tests including short circuit, overcharge and accident damage. The BMAA approved the battery type installed in G-CICF on the basis of testing performed by the manufacturer in 2011, in which the battery was subjected to an overcharge voltage of 24.0 V which caused the battery to fail after 17 minutes 40 seconds without any external visual defect. The battery testing also included a short circuit test which caused the battery to fail after 20 seconds, with minor swelling of the battery case.

TIL 117 requires the installation of a voltmeter visible to the pilot, marked with the maximum permitted battery charging voltage, to permit the pilot to detect if the battery is being overcharged and to then disconnect the battery from the charging circuit. This is intended to mitigate the hazard of any toxic or explosive gases released from the battery if an overcharge event occurs to a battery installed in an enclosed cockpit or cabin area.

LAA lithium-ion battery Standard Minor Modification SM 14337

The LAA also uses a Standard Minor Modification, SM 14337, to approve the installation of lithium-ion batteries in aircraft operating on an LAA Permit-to-Fly. The requirements and guidance in SM 14337 are broadly similar to TIL 117, apart from the list of approved batteries being split in two groups, Group 1 and Group 2. All batteries must be of LiFePO4 chemistry only. Group 1 batteries are permitted to be installed in enclosed occupied areas and must be shown to meet UN DOT 38.3 certification. Group 2 batteries may be installed outside occupied areas, such as forward of a firewall or in a separate fuselage compartment, and do not have to meet UN DOT 38.3.

Footnote

9 CAA CAP 482, British Civil Airworthiness Requirements, Section S – Microlight and Small Light Aeroplanes.

Installation requirements for lithium-ion batteries in Part 21 aircraft

A Part 21 aircraft is defined by the CAA as an aircraft that was previously managed for airworthiness by EASA and was considered an EASA Type. They are regulated under UK Regulation (EU) 2018/1139, also known as the UK Basic Regulation, and its implementing regulations covering airworthiness, operations and flight crew licencing.

Aircraft operating on BMAA and LAA Permits-to-Fly are classified as Non-Part 21 aircraft and are managed nationally under the UK Air Navigation Order. Other Non-Part 21 aircraft include vintage and ex-military aircraft operating on Permits-to-Fly issued by the CAA, and vintage gliders operating on British Gliding Association issued Certificates of Airworthiness.

Installation of systems and equipment on Part 21 aircraft are typically subject to a safety assessment to ensure that, in the event of a probable malfunction or failure of an item of equipment, the hazard to the aircraft is minimised. In the case of a lithium-ion main battery installed in the cabin area, this safety assessment would require the hazards presented by a battery fire to be assessed and mitigated.

Analysis

The lithium-ion main battery in G-CICF was installed in accordance with the requirements of BMAA Minor Modification TIL 117, with the exception that the instrument panel voltmeter was not marked with the maximum charging voltage for the new battery. The battery offered a weight saving and higher capacity than the lead-acid battery it replaced.

No OVP device was fitted between the alternator/voltage regulator and the battery to protect it from a charging voltage above the maximum specified by the battery manufacturer. If the aircraft's CAA A8-1 approval holder had monitored service bulletins issued by the aircraft manufacturer, it is likely that an OVP device would have been required to be installed in G-CICF before the battery fire occurred. However, testing performed during the investigation showed that whilst the charging voltage from the aircraft's alternator/voltage regulator was not constant, it only exceeded the maximum permitted charging voltage by 0.1 V for brief periods. It is therefore unlikely that excessive battery charging voltage from the aircraft's electrical system was the cause of the battery fire.

The cause of the battery fire was not identified due to heat damage to the battery's component parts. The centre of the battery pack, between the terminals, showed the greatest heat damage and it is likely that one of the cells in the centre of the pack was the origin of the thermal runaway.

The battery manufacturer's documentation stated that overcharging, over-discharging, jump starting, use of an incorrect battery charger or physical impact could all damage the battery pack, possibly leading to cell damage and subsequent thermal runaway. The investigation was unable to determine whether G-CICF's battery had been subjected to any such events during the six-year period it had been in service.

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As the battery was within the aircraft's cabin and it was not contained in a sealed compartment with overboard venting, the battery fire resulted in the cabin filling with hazardous gases, smoke and combustion products. This directly affected the ability of the pilot to safely control the aircraft. The actions of the pilot, and his passenger who vented the smoke from the cabin, resulted in a safe landing on this occasion. It is possible that the outcome of a similar battery fire could be more severe. This could occur if an aircraft was flown by a solo pilot who may not be able to vent smoke adequately from the cabin and retain control of the aircraft, or if a prompt landing cannot be made. A second similar battery fire, involving the same aircraft and battery type, shows that the fire in G-CICF was not an isolated event. The following Safety Recommendation is made to the CAA:

Safety Recommendation 2024-006

It is recommended that the Civil Aviation Authority amends the design and installation requirements for lithium-ion main batteries that are located in the cabin areas of Non-Part 21 aircraft, to minimise the hazard to aircraft occupants following a thermal runaway.

Safety action

As a result of this serious incident and the previous similar fire that occurred in Germany, the C42 aircraft manufacturer no longer installs lithium-ion main aircraft batteries in new aircraft, having replaced these with lead-acid batteries.

Conclusion

The aircraft's lithium-ion main battery caught fire during flight, creating smoke and hazardous gases in the cabin that significantly affected the ability of the pilot to safely control the aircraft. The investigation did not identify the cause of the battery fire, but found that the location of the battery within the cabin was a contributory factor in exposing the pilot and his passenger to the hazards generated by the fire.

The investigation made one Safety Recommendation relating to reviewing the installation requirements of lithium-ion main batteries in cabin areas of Non-Part 21 aircraft, to minimise the effect to aircraft occupants following a battery fire.

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