AAIB

Air Accidents Investigation Branch

AAIB Bulletin 4/2024

TO REPORT AN ACCIDENT OR INCIDENT PLEASE CALL OUR 24 HOUR REPORTING LINE

01252 512299

Air Accidents Investigation Branch
Farnborough House
Berkshire Copse Road
Aldershot
Hampshire
GU11 2HH
United Kingdom

Tel: 01252 510300
Media enquiries: 0207 944 3118/4292
http://www.aaib.gov.uk

AAIB investigations are conducted in accordance with Annex 13 to the ICAO Convention on International Civil Aviation, EU Regulation No 996/2010 (as amended) and The Civil Aviation (Investigation of Air Accidents and Incidents) Regulations 2018.

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.

Accordingly, it is inappropriate that AAIB reports should be used to assign fault or blame or determine liability, since neither the investigation nor the reporting process has been undertaken for that purpose.

AAIB Bulletins and Reports are available on the Internet
http://www.aaib.gov.uk

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

Published: 11 April 2024.

Cover picture courtesy of Marcus Cook

ISSN 0309-4278

Published by the Air Accidents Investigation Branch, Department for Transport

CONTENTS

CONTENTS Cont

AAIB CORRESPONDENCE INVESTIGATIONS Cont

RECORD-ONLY INVESTIGATIONS

MISCELLANEOUS

(ALL TIMES IN THIS BULLETIN ARE UTC)

AAIB Field Investigation Reports

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

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

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

Serious Incident

Aircraft Type and Registration:	ATR 72-212A 600, EI-GPN
No & Type of Engines:	2 Pratt & Whitney PW127 turboprop engines
Year of Manufacture:	2015
Date & Time (UTC):	19 September 2022 at 1100 hrs
Location:	Belfast City Airport
Type of Flight:	Commercial Air Transport
Persons on Board:	Crew – 4 Passengers – 32
Injuries:	Crew – None Passengers – None
Nature of Damage:	None
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	40 years
Commander's Flying Experience:	3,900 hours (of which 3,200 were on type) Last 90 days – 164 hours Last 28 days – 50 hours
Information Source:	AAIB Field Investigation

Synopsis

During the aircraft's approach to Belfast City Airport, a number of aircraft systems dropped off-line including some necessary for landing. The flight crew, experiencing natural effects of startle and surprise, and without a specified procedure to follow, continued with the approach, restoring systems by turning off the Transformer Rectifier Unit (TRU). The aircraft was operating under an Operations Engineering Bulletin[1] (OEB) which required the TRU to be continually powered. Following the failure of an electrical contactor, this disconnected the DC output from the TRU to the Standby and Emergency bus bars, thereby removing electrical power to several aircraft systems.

The aircraft manufacturer has taken safety action to improve the guidance for flight crew in the event of a contactor failure when operating under the OEB. In addition, they have introduced a modification which, when embodied, removes the requirement to operate with the TRU permanently powered.

The operator intends to adopt a rule-based method for managing startle, which can help pilots manage workload and maximise their situation awareness before flying an approach.

Footnote

[1] Initiated by EASA Emergency Airworthiness Directive E-AD 2021-0120-E.

History of the flight

Background information

An *'Operations engineering bulletin'* (OEB)[2] (Figure 1) required the aircraft to operate with the TRU ON.

Potential temporary loss of all Cockpit Display Systems

_7c66bf9f-5854-47a8-98cc-205f0918f5af 04 MAY 2021

MSN 1087 / 1097 / 1105 / 1107 / 1169 / 1300 / 1315 / 1322 / 1324 / 1326 / 1334 / 1339 / 1464 / 1471

Procedure

To prevent the temporary loss of all Cockpit Display Systems (including IESI), the TRU must be set **ON** during the "Before Taxi" Procedure and must be set **OFF** during the "After Landing" Procedure.
Use of "BEFORE TAXI" and "AFTER LANDING" Electronic Check Lists is prohibited.
The flight crew must use the QRH
The flight crew must apply :

Normal Procedure:

- **BEFORE TAXI NORMAL PROCEDURE**
  - ▶ TRU.. .... ON & CHECK
- **AFTER LANDING NORMAL PROCEDURE**
  - ▶ TRU.. .... OFF

Normal Check list

- **BEFORE TAXI CHECK LIST**
  - ▶ TRU.. .... ON & CHECK
- **AFTER LANDING CHECK LIST**
  - ▶ TRU.. .... OFF

Figure 1
OEB 56 from the Quick reference handbook

First flight

The crew were scheduled to operate the aircraft from Belfast City Airport (Belfast) to Leeds Bradford Airport (Leeds) and back, then Belfast to Edinburgh Airport (Edinburgh) and back.

The aircraft departed Belfast at 0555 hrs with enough fuel to complete the first three flights[3]. Later, while descending to FL110 inbound to Leeds, a master caution message appeared very briefly, with no associated symptoms. Believing it to be ELEC SBY UNDV, the commander (who was PM), reviewed the relevant procedure in the Quick reference handbook (QRH) (Figure 2). Just after touchdown at 0641 hrs, the same master caution message briefly illuminated, long enough to confirm he had identified it correctly.

Footnote

[2] OEB – contains technical information and temporary procedures to address relevant deviations from initial design objectives.
[3] Fuel can be carried for subsequent flights for economic reasons.

DC STBY BUS UND-V A24.17

- ■ **If DC GEN 1+2 operate**
  - ■ **If one ACW GEN lost**
    - ► HYD BLUE PUMP........................OFF
    - ► HYD X FEED........................ON
  - ► TRU........................ON
  - ■ **If STBY BUS UND/V disappears**
    - ► TRU : KEEP ON
    - MAINTENANCE ACTION REQUIRED
  - ■ **If STBY BUS UND/V persists**
    - ► TRU........................OFF
    - ► HYD X FEED........................OFF AS RQRD
    - ► HYD BLUE PUMP........................ON AS RQRD
    - ► DC STBY BUS FAILURE procedure (A24.16) ....APPLY
- ■ **If DC GEN 1+2 FAULT and TRU not available**
  - ● **For approach only**
    - ► DC STBY BUS........................SELECT OVRD

Figure 2

DC standby bus undervoltage QRH procedure

After parking the aircraft and shutting down its engines, the commander telephoned the operator's airworthiness engineer who suggested powering down the aircraft's electrical system by way of a "re-set". The commander reviewed the aircraft's Minimum equipment list (MEL)[4] to assist with his decision making. He reported the engineer called back with questions about the symptoms of the fault, advising him the underlying cause could be difficult to establish. Therefore, given the transient, asymptomatic nature of the master cautions and the absence of company engineering support in Leeds, they agreed the crew would operate the aircraft back to Belfast for company engineers to investigate further. Both pilots agreed to monitor the electrical system and cancel the departure should any abnormalities occur.

Incident flight

At approximately 0815 hrs, while climbing through FL095 after departing Leeds, the same master caution message occurred for a few seconds. The commander, who was PF, asked the co-pilot to display and monitor the ELEC system display (SD) page on his multifunction display (MFD)[5] (Figure 3), discussing his intention to ground the aircraft on arrival. The co-pilot transmitted blind to the operator on VHF2, by which time they were near the Isle of Man.

Footnote

4 Had the fault latched, the MEL specified *'No dispatch'*.

5 MFD – can display several formats including system display pages or navigation display.

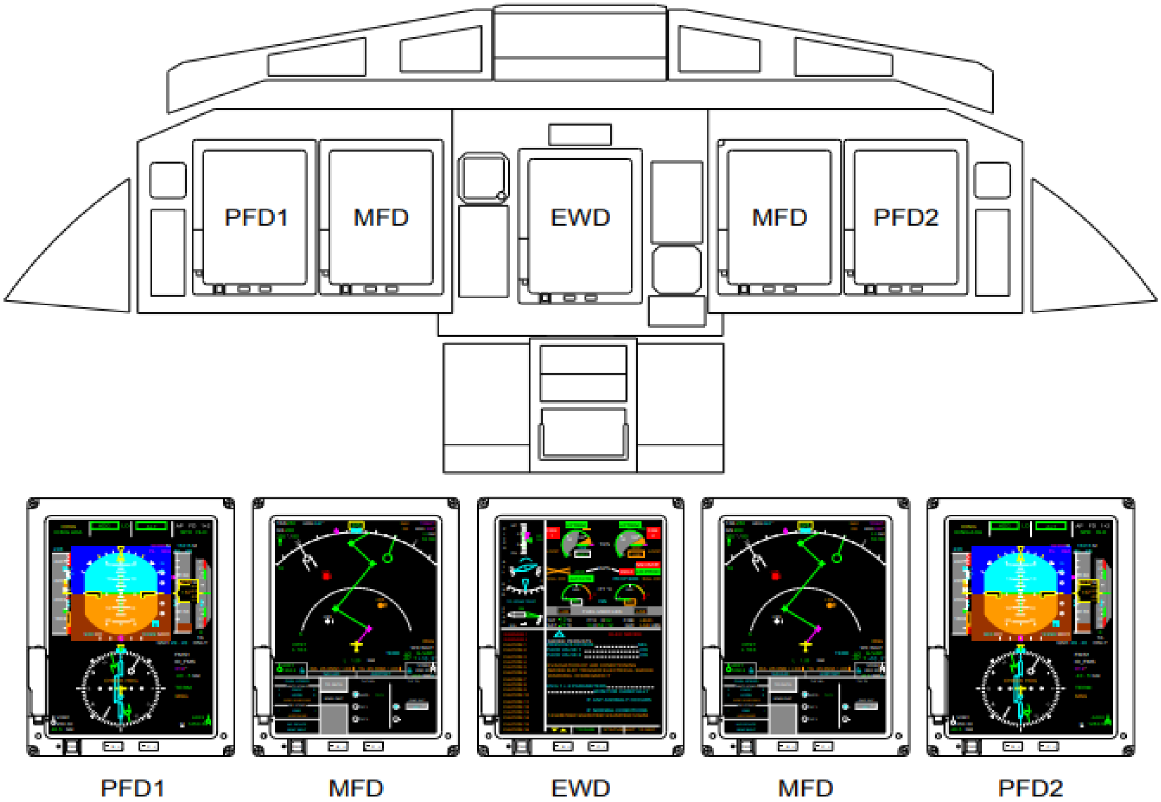

Figure 3

Display unit layout

No further abnormalities occurred until around 0850 hrs when the aircraft was descending through FL82 to altitude 4,000 ft, towards Belfast Runway 22 ILS approach. Recorded data showed a master warning was triggered, and the autopilot (AP) and yaw damper (YD) disengaged. Both pilots recalled some electrical busbars turning amber on the SD page. The flight director (FD) command bars disappeared from their primary flying displays (PFDs), the selected altitude reduced to zero, and the heading bug jumped 180° away from its original position.

Still descending, the crew re-selected cleared altitude 4,000 ft and re-engaged the FD modes, AP, and YD. However, they disengaged again, and multiple failures appeared on the engine warning display (EWD). The flight crew reported believing those included DC STBY BUS UNDV, although the commander recalled the associated 'UNDV' pushbutton light on the overhead panel was not illuminated. On hearing the engines' propeller speeds increase unexpectedly, the commander asked the co-pilot to move the condition levers to 100% OVERRIDE. Another master warning occurred which the co-pilot announced "LANDING GEAR NOT DOWN". Normal pitch trim control stopped functioning such that "a lot of force" was required by the commander to decrease the rate of descent. FAIL flags appeared on the co-pilot's ASI, altimeter, and vertical speed indicator (VSI). The commander recalled his ASI speed bugs disappeared, and his navigation display (ND1) switched from ARC to ROSE mode, and increased range. Using the 'standby instrument'[6]

Footnote

[6] Integrated electronic standby instrument.

and compass, the commander confirmed his remaining PFD information was reliable. The co-pilot continually provided effective monitoring calls about the aircraft's flight path and configuration.

The commander asked the co-pilot to transmit a PAN call to ATC but VHF 1 along with transponder 1 had failed. By the time the co-pilot transmitted it on VHF2, ATC were simultaneously calling the aircraft, having lost SSR contact. The co-pilot reported he was unable to scroll through or select the EWD list of alerts[7], commenting "CAN'T GET ANY OF THESE CHECKLISTS" (Figure 4). Both pilots subsequently reported the screen, including engine instruments, appeared "frozen"[8]. The commander asked the co-pilot to check the circuit breakers and tried unsuccessfully to re-engage the FD modes, AP, and YD.

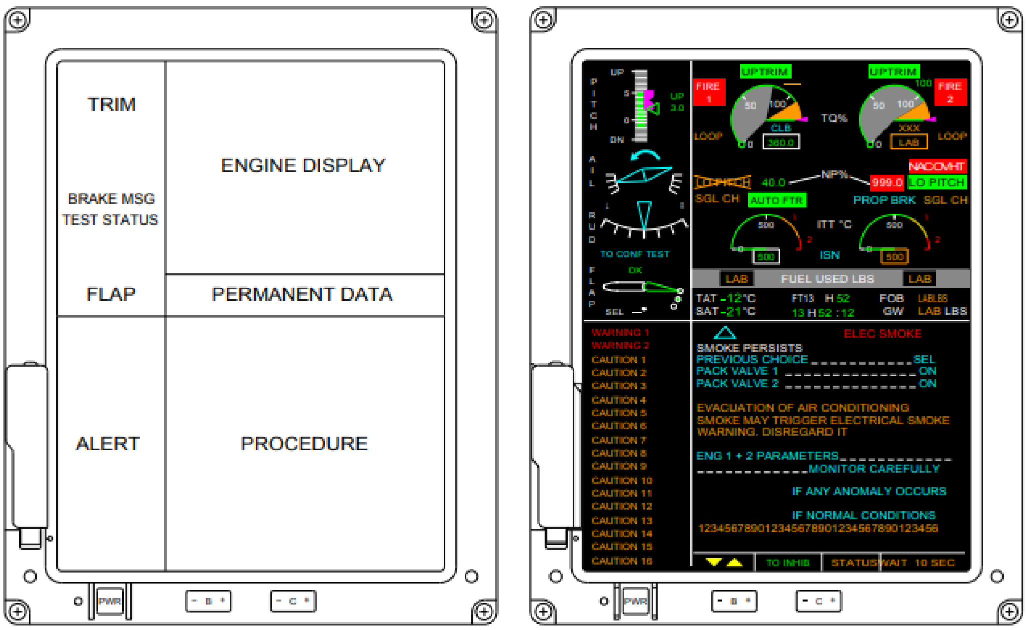

Figure 4

Example Indications on EWD from Flight crew operating manual
(not a representation of the indications presented during the incident)

ATC instructed the crew to fly a heading of 290° and descend to an altitude of 2,000 ft, with 16 nm to touchdown. The commander called the senior cabin crew member to the flight deck for a NITS briefing[9]. Recorded data showed a spurious master caution sounded while the aircraft's electrical network attempted to reconfigure after the DC EMER BUS temporarily recovered.

Footnote

7 A pilot uses their EFIS control panel to select an ALERT, displaying its associated PROCEDURE.
8 The commander said he was "almost certain" the TRQ, NP and NH indications were not functioning.
9 NITS – Nature of situation, Intentions, Time available, and Special instructions.

While on a heading to intercept the localiser, the crew were cleared for the approach. However, realising they had no ILS indications, they requested a visual approach instead. The commander announced they were low on profile and levelled the aircraft at around 1,600 ft amsl before gradually climbing back to around 1,900 ft amsl. Around 8 nm from the runway the crew selected FLAP 15 then landing gear down but neither deployed. The primary landing gear position indicators had stopped working so the co-pilot announced three landing gear UNLK indications on the overhead secondary panel. He reported the only other overhead lights illuminated were the TRU ON and its associated arrow light (Figure 5). The commander asked the co-pilot to check the hydraulic system indications.

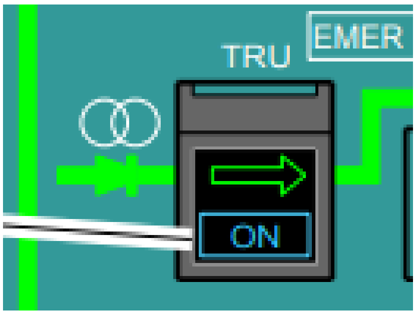

Figure 5

TRU pushbutton on overhead 'Main electrical power' panel

Around 6 nm from the runway, the crew were transferred to Belfast tower frequency. They discussed performing the *'Landing gear gravity extension'* procedure, realising they would need to discontinue the approach to have enough time to do so. However, the commander recalled believing the already difficult nose-down pitch control forces might become problematic during a go-around.

The commander reported that while considering how to resolve the failure, he still had the TRU in mind from earlier on. At 0856 hrs and around 1,900 ft amsl, he instructed the co-pilot to select TRU OFF. Immediately, the display units and normal pitch trim control returned; the landing gear and flaps deployed. The commander reported being right of the runway track with four white 'precision approach path indicator' (PAPI) lights[10] visible. The crew selected FLAP 30, performed the *'Before landing checklist'*, and were cleared to land. The co-pilot stated "ONE THOUSAND ABOVE YOUR SPEED IS GOOD". The aircraft's rate of descent peaked at just over 1,000 ft/min and at 500 ft agl the commander announced he could see two red and two white PAPI lights. The aircraft landed at 0859 hrs.

Weather information

The Belfast weather was reported at 0820 hrs as wind 3 kt from 210°, visibility more than 10 km, no clouds detected and temperature 14°C.

Footnote

[10] Two red and two white PAPI lights indicate the aircraft is on the glideslope. More white lights means the aircraft is high and more red lights means it is low.

Recorded information

EI-GPN was equipped with a solid-state FDR and CVR, capable of recording 2 hours of audio and 25 hours of flight data.

On the flight before the incident flight, as EI-GPN started to descend towards Leeds, the CVR recorded the sound of a master caution. The FDR data showed that the voltage on the DC EMER BUS dropped briefly, from 28 V[11] to 20 V, and that the DC STBY BUS dropped momentarily off-line. On landing, the sound of another master caution was recorded by the CVR, the FDR recorded a brief drop of DC EMER BUS voltage and the crew remarked on the reoccurrence of the electrical problem experienced earlier in the flight. No other voltage transients, or loss of DC buses, were seen on any of the preceding flights recorded by the FDR.

On the return flight to Belfast, at 0814:14Z, as EI-GPN climbed through FL95, the CVR recorded the sound of a master caution and the FDR data showed that the DC STBY BUS dropped momentarily off-line.

Thirty-five minutes later, at 0849:15Z, as EI-GPN descended towards Belfast passing through FL82, a master warning was triggered, and the AP and YD disengaged. The FDR data showed that the loss of AP and YD functionality, see point A on Figure 6, was coincident with a voltage drop on the DC EMER BUS and loss of the DC STBY bus, as had occurred on the previous flight, but both buses recovered quickly. The AP and YD were then re-engaged by the crew.

Twenty-eight seconds later, at 0849:43Z, a further master warning was generated as the AP and YD disengaged again (point B), and the DC EMER BUS and DC STBY BUS dropped off-line. Simultaneously, the propeller speed for both engines increased towards 100%[12], as the propellers' governors were affected by the reconfiguration of the aircraft's electrical network caused by the loss of the buses. The radio altimeter signal also became invalid and the change in status of this signal triggered a master warning, associated with the landing gear not being selected down, as this alert relies upon the radio altimeter to sense proximity to the ground. However, unlike the previous occurrences, the DC EMER BUS and DC STBY BUS did not recover and both buses then remained unpowered for the next four and half minutes.

Footnote

[11] 28 V is the nominal voltage of the DC buses on the ATR72-212A.

[12] The propeller speed for both engines thereafter remained at 100%, as the crew manually re-positioned the propeller condition levers to 100%.

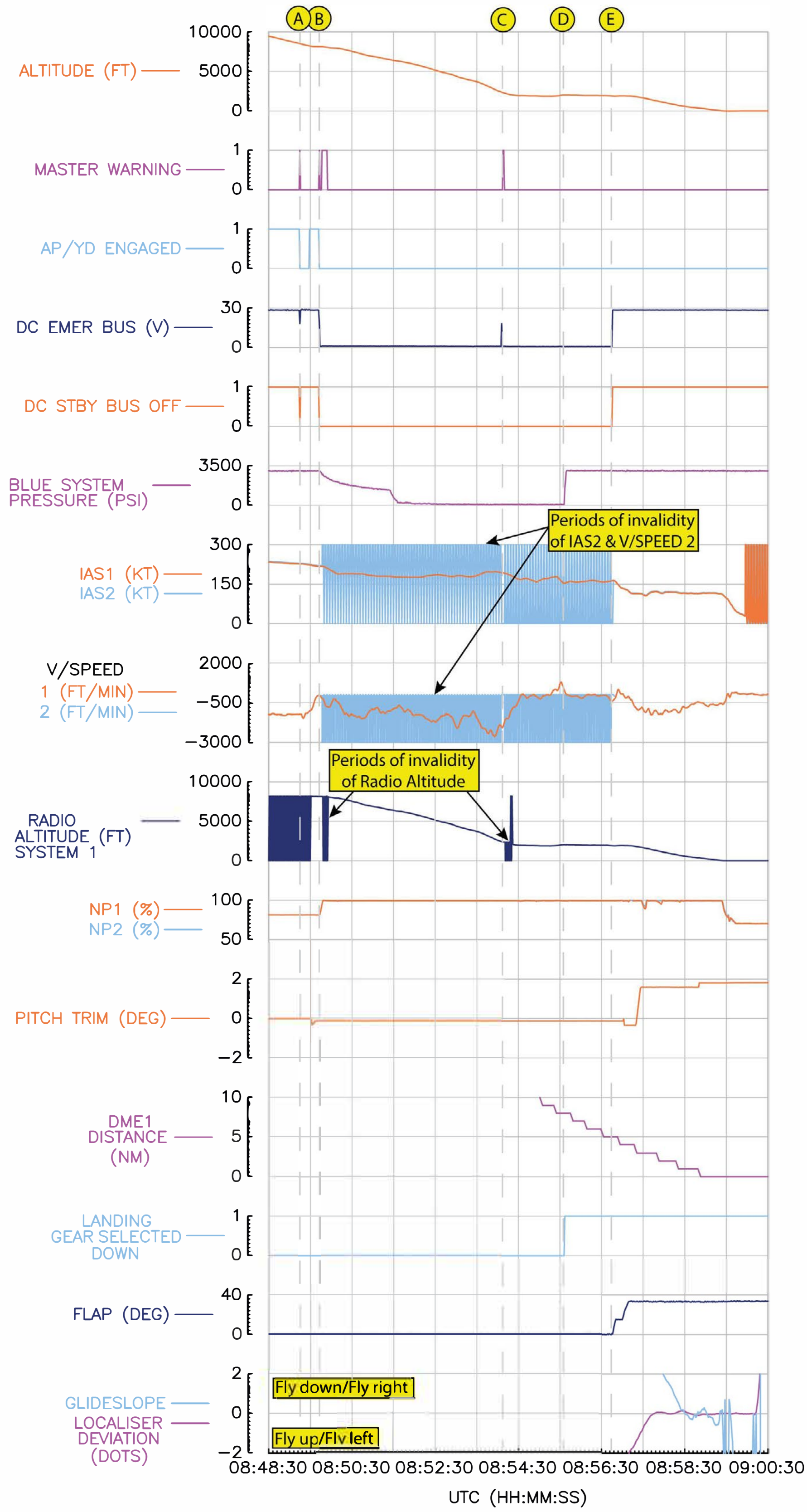

Figure 6

Flight data for the incident flight from just prior to the loss of AP and YD, until after landing.

The FDR data showed that throughout this time, as the crew continued their approach towards Belfast (Figure 7), the functionality of several systems was lost. These included:

- The co-pilot's air data computer (ADC); this resulted in no airspeed, altitude, and vertical speed data displayed on the co-pilot's PFD[13],
- the blue hydraulic system required for flap extension and the roll spoilers,
- the normal pitch trim system[14],
- the normal landing gear extension system,
- some secondary engine instrumentation for the left engine,
- VHF radio number 1 and the transponder.

Figure 7

Approach towards Belfast from just prior to the loss of AP and YD, until after landing.

At 0854:06Z, as EI-GPN descended through 2,400 ft amsl with approximately 12 nm to run to Belfast, the voltage of the DC EMER BUS recovered momentarily (Figure 6 point C), and then dropped again. This resulted in a further spurious master warning, associated with the landing gear not being selected down, as EI-GPN's electrical network attempted to reconfigure. However, both the DC EMER BUS and DC STBY BUS remained unpowered for a further 2½ minutes.

Footnote

13 The Commander's ADC remained operational, but this was not selected for display on the co-pilot's PFD.

14 The standby pitch trim system remained operational, but the FDR data showed that the stabiliser's position did not change during the loss of power to the DC buses.

At 0855:37Z, approximately 8 nautical miles from touchdown, and passing through 2,000 ft amsl, the crew selected the landing gear down (Figure 6 point D). However, the sound of the landing gear travelling was not recorded until passing through 1,900 ft amsl at 5 DME, when the crew turned off the TRU at 0856:45Z (point E). This action restored power to all the affected DC buses, however, the blue hydraulic system had already re-pressurised on selection of the landing gear down.

Shortly afterwards, at 0856:47Z, landing flap was selected and EI-GPN decelerated from 160 kt to 120 kt. During the latter stages of the approach, for periods of up to several seconds at a time, the descent rate exceeded 1,000 ft/min. EI-GPN landed safely at 0859:29Z.

Information from the operator

The operator commented that selecting the TRU on usually involved "substantial switching" which could affect other systems. It queried using an emergency back-up system for lengthy periods during normal operations.

After the incident, the operator released a 'Safety notice' to its flight crew, explaining what happened and asking them to report any electrical anomalies. Some days later the advice was formalised in a *'Temporary flight crew instruction'* which stated:

> *'Effective immediate. Any momentary losses of electrical equipment or loss of EMER, ESS, or STBY BUSSES must be entered in the tech log and ACE contacted immediately.*
>
> *In addition, if flight crew experience a temporary indication of undervoltage on the overhead panel, no matter how momentary, it must be entered in the tech log and ACE contacted immediately.*
>
> *For any such events, flight crew must also submit a SMS[15] 360 report.'*

Having recreated the incident conditions in its own simulator session, the operator indicated the failure symptoms were challenging and observed that OEB 56 did not include an abnormal procedure to identify, troubleshoot and resolve the failure.

The operator stated its intent to maximise learning from the event.

Additional information from the flight crew

The commander explained some complexity in applying the *'DC STBY BUS UND-V'* QRH procedure during the first flight. Relevant conditions required the TRU to be selected ON, whereas it was already ON under OEB 56. With that still in his mind while considering how to resolve the failure during the incident, the TRU's illuminated indications (Figure 5) prompted him to turn it OFF. He described preferring to return the aircraft to, what he called, its "original design" – meaning its electrical configuration prior to the release of OEB 56.

Footnote

15 Safety management system.

The CVR showed characteristic effects of startle, surprise and stress in the flight crew's communication and information processing while the failure unfolded. With no clear cause, or procedure to follow, the commander reflected on the strength of startle effect during a real failure compared with simulator training. He stated "the aircraft had a lot of failures, including the system which tells you what failed". He said the high pitch control forces made it "just about manageable to fly the approach". It did not occur to him at the time to use standby pitch trim control. He reported the co-pilot's instrumentation failures meant that passing control of the aircraft to him did not seem like a good option. Reflecting on a previous simulator training session during which an electrical fault caused smoke in the flight deck, the commander had wanted to land EI-GPN as soon as possible.

The co-pilot described his PFD and MFD had "red crosses everywhere". He was particularly surprised at being unable to access the EWD procedures using his EFIS[16] control panel (EFCP-R), commenting "I remember pushing the buttons hard and returning to it at least a couple of times as I found it hard to believe it was not working… it seemed… the screen just froze, and the checklists were never going to work no matter what buttons I pressed or how hard I pressed them". He was fairly, though not completely, sure he tried the commander's EFCP-L without success.

CVR evidence indicated supportive and intuitive teamwork between the crew.

Additional information from the operator's Operations manuals

The operator's Operations manual Part B (OMB) contained the operator's *'Stabilised approach criteria'*. Relevant parts include:

> *'An approach is considered stabilised when all of the following conditions are met.*
>
> - *The aircraft is on the correct flight path.*
> - *Only small changes in heading or pitch are required to maintain the correct flight path.*
> - *The aircraft is in the correct landing configuration.*
> - *All checklists and briefings are complete.*
> - *The aircraft speed is Vapp (with wind corrections) +10kts/-0kts.*
> - *Descent rate is less than 1000 ft/min (if the approach requires a higher descent rate, this must be covered in the briefing).*
> - *Power is set correctly, according to aircraft weight and conditions…*
> - *The visual segment of any approach must be flown with reference to the PAPIs, where available, to within not more than one light deviation high or low.'*

Footnote

[16] EFIS - Electronic flight instrument system.

OMB specified an aircraft must be stabilised by *'500ft. aal'* although the operator reported that had recently changed to 1,000 ft aal. Otherwise, a missed approach must be performed.

OMB stated *'Pilots should use the TDODAR decision-making process to manage abnormal occurrences'.* It stands for *'Time… Diagnosis… Options… Decision… Assign/Action Tasks… Review and Risk Assessment'.*

Aircraft description

The Avions de Transport Régional (ATR) 72-212A-600 is a short-haul twin turbo-propeller passenger aircraft. The aircraft can carry up to 72 passengers and has a MTOW of 23,000 kg with a range of 1,500 km. The 600 series ATR aircraft are fitted with fully integrated digital cockpit displays including the single integrated electronic standby instrument (IESI). It also has a full authority automatic flight control system and ILS.

Aircraft electrical power supply and distribution system

The aircraft electrical power requirements are supplied by the following:

- Two 24 V DC nickel cadmium batteries (main and emergency) which supply the critical DC electrical loads in flight should the DC generated supplies be lost. They have the capacity to sustain up to 30 minutes of power to essential systems. The main battery supplies power for engine start.
- Two 28 V DC starter generators driven by the accessory gearbox on each engine.
- Two Static Inverters are supplied with DC Power to produce 26 VAC & 115 VAC constant frequency (400Hz).
- Two 115/200 V three-phase AC wild (ACW) generators are driven by each propeller reduction gearbox. These will produce a frequency range of 341 to 488 Hz.
- A transformer rectifier unit (TRU) converts ACW power to DC power for emergency use in the case of the loss of both DC generators.
- Ground power receptacles and control circuitry allow the connection of 28 V DC and 115 VAC at 400 Hz from an airfield supply or ground power unit.

In normal operation the DC generators supply power to DC BUS 1 (Right/Green) and DC BUS 2 (Left/Red). BUS 1 & 2 supply power to the utility (UTLY) BUS 1 & 2, service (SVCE) BUS, emergency (EMR) BUS, standby (STBY) BUS and essential (ESS) BUS. If one of the generators fail, the generator control unit (GCU) and BUS power control unit (BPCU) allows power to be distributed to DC BUS 1 and 2 simultaneously via a BUS tie contactor.

If both generators fail, DC Emergency Electrical network (DC EMER BUS, DC STBY BUS and DC ESS BUSES) are respectively supplied by main and emergency batteries through the HOT EMER BAT BUS and the HOT MAIN BAT BUS. In addition, providing there is ACW power available, the TRU can be selected by the pilot to supply 28 V DC power to the DC EMER BUS via a contactor designated 95PA and to the DC ESS BUS via another contactor designated as 96PA.

Change to the power distribution system operation

As a result of two previously reported temporary losses of the cockpit display units and IESI, an EASA Emergency Airworthiness Directive E-AD 2021-0120-E was released. It identified that the probable cause was likely to be the failure of battery master toggle switch, known as functional ident number (FIN) 7PA, or a failure of contactor FIN 1PA. To mitigate the risk of the ATR 42-500 post MOD 05948 ("600 version") and ATR 72-212A post MOD 05948 ("600 version"), ATR required physical testing and examination of these components and replacement if necessary. In addition, to reduce the risk further, all flights were to be carried out with the TRU selected ON from initial start-up of the aircraft to shut down on completion of the flight. The QRH was amended accordingly. This applied to EI-GPN which was being flown within the requirements of this AD. In this configuration the DC generators supply the main BUS 1 & 2 and the TRU supplies the DC EMER, ESS and STBY BUS. Figure 8 shows the DC system with the TRU in operation.

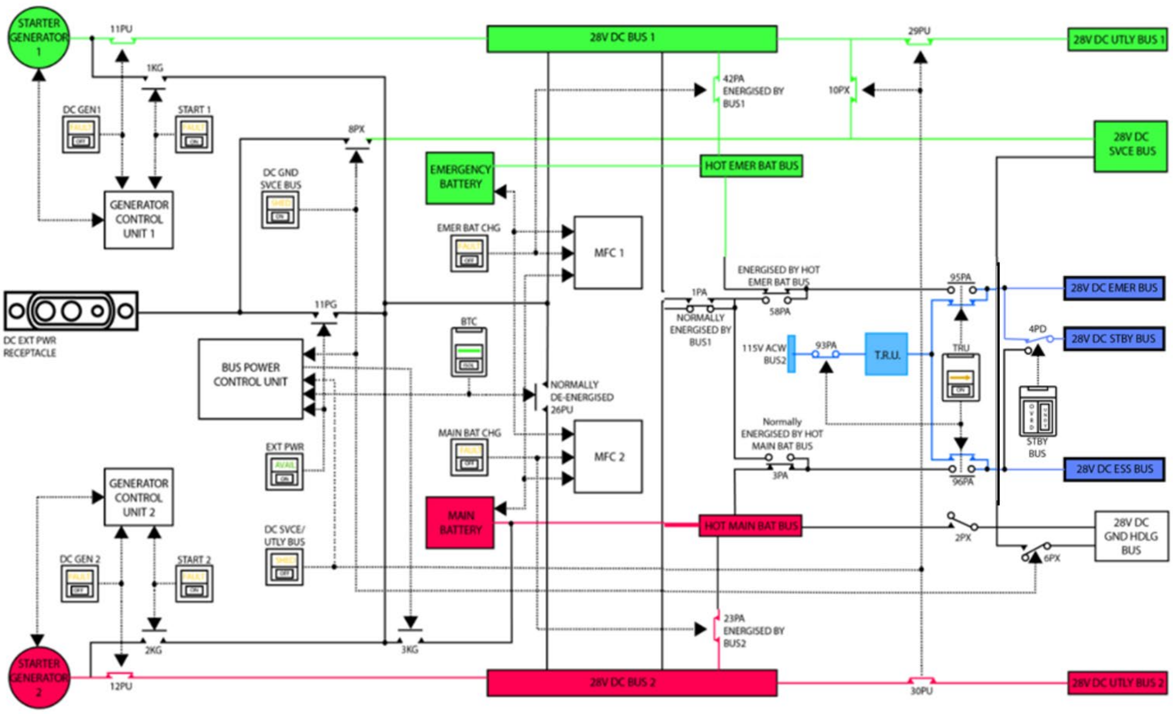

Figure 8

DC power supply configuration during the flight.

Contactor description

The application of electrical power to the various busbars is carried out by an array of remotely controlled contactors on a distribution panel on the rear right side of the cockpit. The 1PA, 95PA and 96PA contactors are the same part number, SM150D19, and have the same specifications. Figure 9 shows the array of contactors within the distribution board in the aircraft, the 95PA contactor is on the bottom right of the picture.

Figure 9
The 95PA contactor as fitted to EI-GPN

The SM150D19 contactor is a device designed to allow remote control switching in high current applications. These contactors are generally used to allow light current switches to be used on instrument and control panels, reducing the need for bulky switch gear and cabling where space is at a premium.

Contactor operation

A schematic of the SM150D19 contactor is shown in Figure 10. In the dormant or deenergised condition, a small spring holds the plunger carrying the contact plate (shown in green) against main contacts B3 and B2. The auxiliary contacts operate simultaneously with the main contact plates as the contactor is energised and de-energised. They direct voltage to illuminate status indication graphics within the electrical system cockpit control switches.

When a voltage is applied to the solenoid terminals 7 and 8, on selection of the TRU, the plunger moves against spring force and the contact plate moves away from contacts B3 and B2 breaking the circuit. As it continues moving, the lower contact plate (shown in orange) is pulled against contacts A1 and A2. At the same time, auxiliary contacts 6/2 open and 9/5 are closed[17]. Continuity between main contacts A1 and A2 remains whilst the solenoid is energised. A suppressor is fitted across terminal 7 and 8 to prevent the back EMF, generated as the plunger moves in its magnetic field, from damaging the control switch gear.

Footnote

[17] Auxiliary contact number 6 and number 2 (Contactor 95PA de-energised) provide an electrical ground to illuminate the emergency battery arrow caution in case of emergency battery discharge. Auxiliary contact number 9 and number 5 (Contactor 95PA energised, TRU engaged), provide a 28 VDC from TRU output, to illuminate the arrow of TRU switch to indicate that the TRU is engaged and operational. Contacts 1 and 4 are unused and are open circuit.

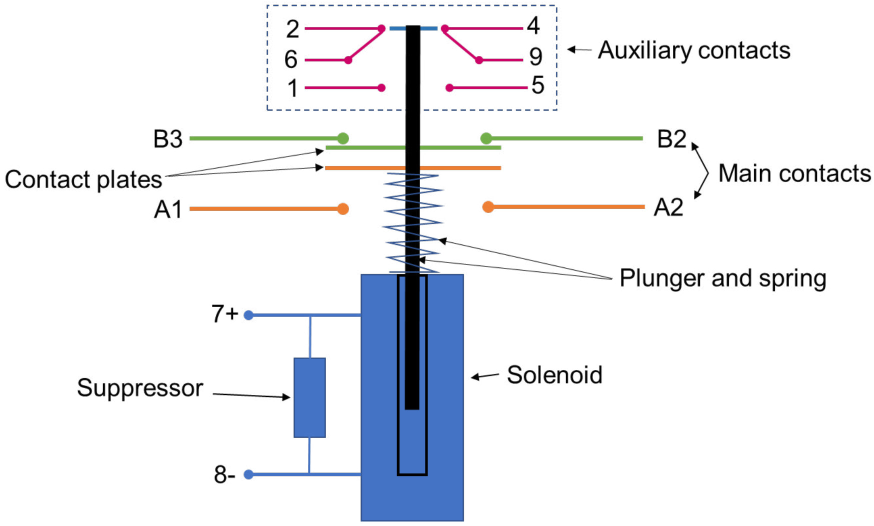

Figure 10

Contactor schematic diagram (shown de-energised)

The plunger assembly consist of two parts; the plunger and plunger pin. The plunger pin is held in a hole drilled in the plunger by a form of interference[18] fit. (Figure 11). During manufacture the minimum force required to insert the pin into the hole is 70 lbs. When correctly assembled, the force required to withdraw the pin, known as the pull-out force, is 80-100 lbs.

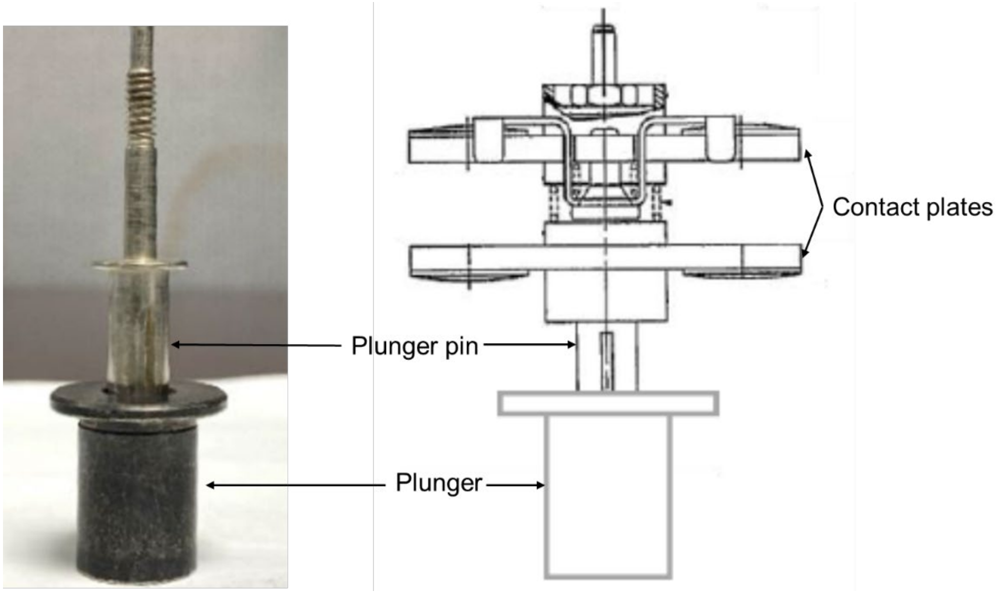

Figure 11

Plunger and pin assembly
(The plunger and pin photograph shows both components prior to insertion)

Footnote

[18] Form of interference fit – in this case the diameter of the hole in the plunger of the pin are dimensionally the same. During pin manufacture a groove is indented length wise on the surface of the pin. This has the effect of displacing material upwards on either side of the indentation slightly increasing the pin diameter in those areas. When the pin is inserted in the plunger hole this raised material creates a localised interference fit between the raised material and plunger hole surfaces.

Hydraulic systems

The aircraft is fitted with two hydraulic systems, designated as the blue and green systems. Hydraulic pressure is supplied at 3,000 psi in both systems by electrically driven pumps powered by the ACW electrical system. The blue system pump takes its power from AC BUS 1 and the green pump is powered from AC BUS 2. The blue system pump control and alerts take their power from the DC EMER BUS. The green system pump control is powered by the DC ESS BUS SECT 2 and its alerts are powered by the EMER BUS.

The blue hydraulic system powers the nosewheel steering, flaps, roll spoilers and propeller brake. It also charges the emergency brake accumulator for the parking and emergency wheel braking system.

The green system powers the landing gear and normal wheel braking.

Flying control systems

The aircraft is fitted with conventional servo tab elevator, rudder and aileron flying controls. The controls are operated via cables, pulleys and bell-cranks. Electrically driven autopilot actuators and control surface trim actuators are fitted within each of the systems.

Pitch trim system

The pitch trim system consists of two electrically driven actuators which move the servo tabs, fitted to the left and right elevators, up or down to achieve the desired trim. They are synchronised in normal operation and are able to desynchronise should one of the servo tabs malfunction. The trim actuators take 28 V DC from the EMER BUS and are controlled by double toggle switches on both control yokes. The trim actuators also receive control input demands from the automatic flight control system and automatic trim system. If the pitch trim system loses normal power supply a simple standby pitch trim guarded toggle switch may be used. The standby trim system takes its power from DC BUS SECT 2.

Landing gear control system

The green hydraulic system provides hydraulic power to retract and extend the landing gear. The system is operated by a toggle lever on the cockpit centre panel. The lever is located in up and down detents and must be pulled outwards to release it from the relevant detent. Three illuminated landing gear status indicators are located above the lever. Landing gear electrical control and primary indication and warning is supplied from the STBY BUS. Landing gear secondary indication is taken from DC BUS 2 SECT 1.

Aircraft examination

The aircraft was quarantined and examined at Belfast City Airport. Ground electrical power was applied, and the aircraft systems and displays were configured as they had been at the time of the incident. The engines and therefore generators were not running. On selection of TRU ON, numerous systems dropped off-line and DC STBY BUS and EMER BUS also indicated offline. The aircraft system status pages confirmed that this was the case. When the TRU was selected OFF, the systems returned to normal. With the aid of the aircraft circuit diagrams and the assistance of the operator's line engineer, a malfunction of the 95PA contactor was identified as the most likely cause. System functional checks carried out on the aircraft confirmed this was the case. The 95PA contactor was replaced and further testing of the systems and operation of the TRU corroborated this. The aircraft was released back to the operator and placed back into service; there has been no recurrence of the malfunction.

Contactor testing

A decal on the cylindrical solenoid casing of the contactor shows the part number, specifications and contactor internal circuit diagram. An alpha numeric code was printed on the contactor frame which read, 'MFD 1513'. This is a code which means that this contactor was manufactured during week 13 of 2015.[19]

EI-GPN was built during 2015 but it is not known if this 95PA contactor was fitted at that time. These components are not serial numbered or tracked and are not under a service life policy, the 95PA contactor may have been installed during the build process.

Preliminary visual examination and continuity testing was carried out at the AAIB with the contactor in the de-energised condition. The contactor was undamaged and in good condition. The solenoid coil resistance was found to be 50.1 ohms and therefore was within the manufacturer's specification. There was electrical continuity between terminals B2 and B3 which was correct when in the de-energised condition.

The contactor was sent to the manufacturer for a more detailed test and examination under the supervision of the National Transportation Safety Board (NTSB) Accredited Representative. A test load of 150 A was connected to the main terminals A1/A2 and B2/B3. Several energising and de-energising cycles were carried out and during a fifth cycle, the A1/A2 terminals remained open when the contactor was energised. They should have been closed when in this condition. The B2/B3 terminal worked correctly, so were closed when de-energised and open when energised. In addition, it was found that the auxiliary contacts, 1/6, 2/6, 4/9 and 5/9 operated correctly in the de-energised condition but incorrectly in the energised condition.

The contactor was disassembled and it was found that the contact surfaces on the contact plate and on the A1/A2 contacts showed evidence of arcing and poor connection. Further examination found that the pin had slipped 0.0196 inches out of the plunger hole. A pull-out test was also carried out and the pin moved with a force of 18 lbs. The minimum pull-out force should have been 80-100 lbs.

Tests and research

During this investigation five other SM150D19 contactors in use in the 95PA and 96PA circuit locations failed in other aircraft. These were examined by the OEM in conjunction

Footnote

19 The SM150D19 manufacturer's warranty is 3 years from the date of manufacture.

with the contactor from EI-GPN. It was found that the pin had moved within the plunger in all these contactors and they exhibited a pull-out force of between 18 and 30 lbs. Three of these contactors were manufactured during 2015. The other two were manufactured in 2019 and 2020. Metallurgical and dimensional analysis was then carried out on the pins and plungers.

The material specification, hardness and plating treatments on the pin and plunger in all cases were found to be correct. Slight dimensional variations were found in the pin indentation and pin insertion depth when compared to the design specifications, but these were within tolerance.

As a control, pin and plunger pull-out and dimensional tests were carried out on sets of high cycle contactors made between 1995 and 2007. Another set of contactors made during 2023 were energised and de-energised over 50,000 mechanical (100,000 electrical) cycles over a period of nine hours at an ambient temperature of 71°C. The pull-out test carried out on the older 1995 to 2007 pins and plungers found three of them to exceed the 100 lbs force required and one with a pull-out force of 94 lb. There was no pin slippage in these assemblies. The newer 2023 set all exhibited pull-out figures of between 80 and 91 lb and there was also no pin slippage.

Example plungers taken from older and newer assemblies were sectioned and measured. This found the dimensions of some of the older pin groove indentation marks left in the bore of the plunger were less than those marks in newer plungers. Figure 12 shows the difference in the dimension with a mean of 0.0245 inches in the older plunger and a mean 0.0319 inches in the newer plunger.

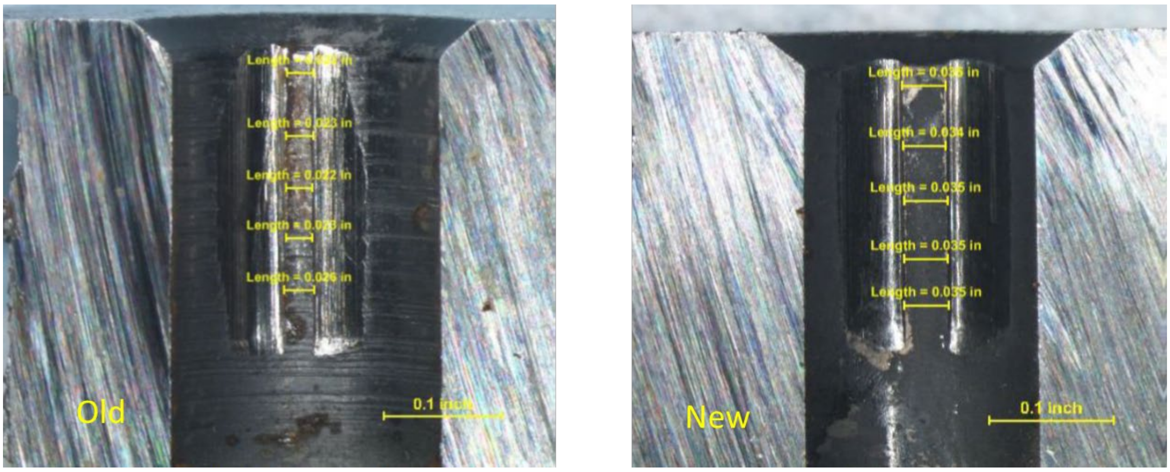

Figure 12

Plunger bore dimensions of the grooves left by the pin

Simulator session and discussions with manufacturer

Overview

The AAIB attended a simulator session at the manufacturer's headquarters on 25 November 2022 to explore the technical and procedural aspects of the event, using the incident location and flight conditions. With no function to simulate the 95PA contactor failure, the incident conditions were recreated by failing the DC SBY BUS[20] then the DC EMER BUS, and inverter 1 (Figure 13). Consequently, the manufacturer estimated the technical aspects of the simulation were accurate but that anomalies were possible.

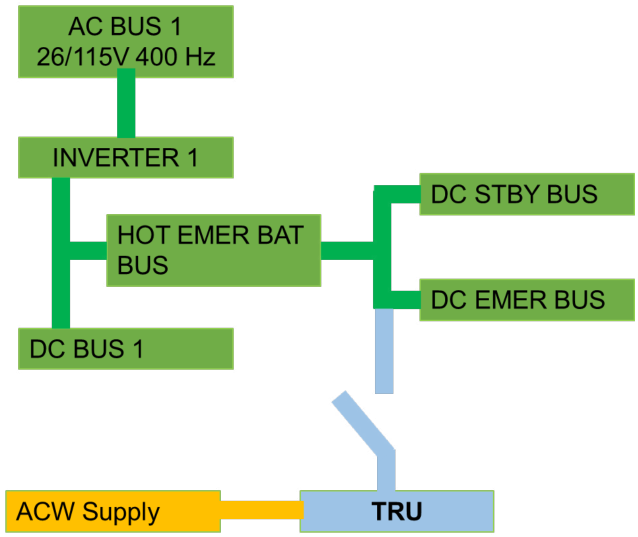

Figure 13

Simulator circuit configuration to recreate the loss of DC STBY BUS and DC EMER BUS

The simulator pilots demonstrated resolving the failure while in a holding pattern using OEB 56 Issue 3, which was published after the incident[21] (Figure 14). Accordingly, the session was not intended to assess any real startle or surprise experienced by EI-GPN's crew. The manufacturer indicated it recognised the significance of the failure for an unsuspecting crew. It said it might anticipate crew taking time to perform outstanding procedures before flying an approach, using the EWD or QRH as necessary.

Lost equipment

The *'DC EMER BUS OFF'* and *'DC STBY BUS FAILURE'* QRH procedures, and discussions with the manufacturer indicated a substantial list of lost equipment including autopilot, VHF1, multipurpose control panel[22] 1, normal pitch trim control, rudder trim, aileron trim, blue hydraulic pump, transponder 1, a navigation process module[23], and a significant number of indication lights. Some de-icing boots and all anti-icing controllers would be lost, requiring the crew to *'leave and avoid… icing conditions'*. A persisting failure would

Footnote

20 Flight crew typically deal with alerts in the order they are presented.
21 Publication date 30 November 2022.
22 Used to control the virtual control panel format on MFD.
23 Core processing module (CPM) 1.

require the *'Landing gear gravity extension'* and *'Reduced flaps landing'* procedures to be performed. Nosewheel steering and outboard anti-skid would be unavailable. However, under the circumstances of the incident, the *'DC EMER BUS OFF'* and *'DC STBY BUS FAILURE'* QRH procedures required selecting the TRU OFF.

Simulator session

The simulator session and associated discussions demonstrated standby pitch trim control would have functioned during the incident. The co-pilot's ADC switch[24] would have retrieved PFD information on his side. One flight director and one ILS display might have been available. The LANDING GEAR NOT DOWN warning occurred because one radio altimeter failed with the power levers at FLIGHT IDLE. The manufacturer suggested that, rather than all the engine instruments being "frozen", there were crosses on some of them, while others – for example, TRQ, NP and NH[25] – probably remained operational. Losing the propeller electronic control (PEC) caused the increase in NP. During the simulation, FMS 1 failed. Unlike the incident pilots' recollections, the heading bug, altitude preselect, and VSI remained unaffected, and EFCP-R functioned while EFCP-L did not.

IN FLIGHT

In case of alert:

- **ELEC DC EMER**, or
- **ELEC DC ESS**, or
- **ELEC DC SBY BUS**, or
- **ELEC STBY UNDV**, or
- **FWS not avail** and **PACK 1+2 Fault**.

Before performing the associated procedure(s):

▶ TRU.. OFF

■ **If the bus is recovered**

▶ TRU : MAINTAIN OFF UNTIL END OF THE FLIGHT, EVEN IF TRU ON IS REQUESTED IN A SUBSEQUENT PROCEDURE.

Note
Check and, if necessary, restore the equipment(s) of the recovered bus (AP, air conditioning/ pressurization, baro settings, Navaids, FMS, ...).
TRU is considered as inoperative.
Maintenance action will be required at destination.

■ **If failure persists**

▶ **LAND ASAP**

▶ TRU : MAINTAIN OFF UNTIL END OF THE FLIGHT, EVEN IF TRU ON IS REQUESTED IN THE SUBSEQUENT PROCEDURE(S).

▶ ASSOCIATED PROCEDURE(S).. APPLY

Note
Only one EFCP Procedure Control pushbuttons side is operative.

***

In case of:

- AUTO-PILOT (AP) disconnection, and

Note
AP remains available.

- TRU arrow light comes off.

Perform the following procedure:

▶ TRU.. OFF

Note
Maintenance action will be required at destination.

Figure 14

Excerpt of updated OEB 56 (Issue3)

Footnote

[24] Displays ADC information from the Captain's side.
[25] NH is displayed on the Engine SD page.

The *'Flight crew training manual'* (FCTM) for the aircraft specified *'SOP[26] Golden rules'*, which included *'FLY, NAVIGATE, COMMUNICATE – IN THAT ORDER'*.

Startle and surprise

The International Civil Aviation Organization's (ICAO) website included a presentation on managing startle[27]. It specified *'Cognitive effects of startle'* including *'Information processing tasks such as attention, perception, situational awareness, problem solving and decision making can be markedly impacted… Communication is often disorganised and incoherent for some time.'*

The European Union Aviation Safety Agency (EASA) published a research project on *'Startle effect management'[28].* It stated:

> *'…in an unclear or ambiguous situation… high levels of physiological and psychological stress can persist.*
>
> *…when the fight or flight response is strong… [it] creates a sense of urgency to take action, perceived time pressure. This action-mode inhibits slow and deliberate analysis.*
>
> *The duration of the surprise response is typically longer than that of the startle reflex. The discrepancy between expected and actual circumstances requires the person experiencing the surprise to reevaluate the situation to continue with the task… people tend to focus on the most salient information, which may not be the most important information at that moment (Rivera et al, 2014).'*

An academic paper[29] on pilot stress, startle and surprise, quoted the authors of a relevant model as saying *'…stress is thought to cause a shift from analytical skills toward intuitive judgement, making one susceptible to biases'.* Plan continuation bias means continuing with the original plan despite cues indicating a different plan is preferrable. It often occurs in dynamically changing conditions.

The CAA of New Zealand's *'Situation awareness'* document stated[30] *'We have limited ability to divide attention amongst tasks and generally, have to switch attention back and forth between tasks'.*

Footnote

26 Standard Operating Procedure.
27 Microsoft PowerPoint - Managing Startle Individual Crew and Organizational Strategies Wayne Martin (icao.int) [accessed 27 July 2023].
28 R:\SM1\1.1 SAR\1.1.2 RCO\6_PROJ_EASA\Research\2015\2015.C22 Startle Effect Management STEM\3-Deliverables\Final Report\research-project-cover-page (europa.eu) [accessed 27 July 2023].
29 Frontiers | A narrative review of the interconnection between pilot acute stress, startle, and surprise effects in the aviation context: Contribution of physiological measurements (frontiersin.org) [accessed 27 July 2023].
30 Situational awareness guidance (aviation.govt.nz) [accessed 5 May 2023].

The UK CAA's *'Civil Aviation Publication 737'* (CAP 737)[31] stated the following under *'Surprise and startle'*:

'…the alarm element of the fight or flight[32] *response also appears to have an immediate and sustained impact on our cognition. Almost all mental capacity becomes focussed on the threat and/or the escape from it…* [It] *is accompanied by an urge to be engaged in the active solution… But if resources are not given to assessment and problem solving then the person cannot decide the best response. This situation would be best described as a vicious circle'.* It suggested to *'align the task expectation in a way that recognizes the cognitive response'*, with *'linear, simple, rule*[33]*-based responses'* being *'preferred in such situations… The classic rule of 'aviate, navigate, communicate' is a very good starting point in most cases…'.*

Its *'Situation awareness'* chapter suggested pilots can use a systematic process, for example, *'Rotate attention from plane to path to people (aviate, navigate, communicate)…'* any time they need to.

Some operators use models like *'plane, path, people'* to help crews maintain situation awareness and manage startle. This operator expressed keenness to maximise learning from this incident, and stated its intent to adopt a 'rule-based' structure for assisting its crews accordingly.

Analysis

Electrical system failure

The electrical system failures during the approach to Belfast City Airport was caused by a malfunction within the SM150D19 contactor designated as the 95PA contactor. Within the circuit, it supplies 28 V DC output from the TRU to the STBY and EMER BUS bars. On this occasion, whilst 95PA was in the energised condition continuity was lost between the A1 and A2 terminal contacts. This was caused by the pin carrying the contact plate slipping out of its correct position as a result of its movement within the plunger.

The results of the metallurgical and dimensional tests were inconclusive. However, the combination of tiny differences may have coalesced to allow the slippage of the pin and plunger in a batch of contactors made during 2015 and two outliers made in 2019 and 2020.

Based on the year that EI-GPN was built, 2015, and the contactor date of manufacture, it is likely this was the original item fitted at aircraft build. Until the introduction of the E-AD 2021-0120-E, ordinarily the 95PA and 96PA contactors remained in a de-energised condition other than for occasional routine testing of the TRU. However, after introduction of the AD, these contactors were now required to remain in an energised condition throughout the flight.

Footnote

[31] CAP737 Flight-crew human factors handbook (caa.co.uk) [accessed 27 July 2023].
[32] Fight or flight – physiological response to threat. Subtly different to startle reflex although they can both occur in response to the same threat.
[33] From Rasumussen's *'Skill Rule Knowledge'* model. Rule-based responses are suited to abnormal situation management because they require less conscious effort than knowledge-based ones, and can be more reliable than more instinctive skill-based responses.

There are numerous SM150D19 contactors used in this aircraft type and many of them are regularly held in the energised condition whilst in service without any problems. However, in cases where they have failed, the result has generally not been as noticeable because fewer systems have tripped off-line and have been routinely dealt with by referring to a procedure set out in the QRH. In these cases, the aircraft then continues with the flight and lands safely with the malfunctioning contactor being replaced as required and the aircraft released to service. In this case, the 95PA contactor affected quite a broad range of seemingly unrelated systems via the STBY and EMER BUS BARS and the failure of this combination was not covered by a specific procedure in the QRH. It therefore was more difficult for the pilots to troubleshoot and eventually resolve.

E-AD 2021-0120-E was developed and issued to address the potential problems with the 7PA battery master toggle switch the and FIN 1PA contactor. It is possible the in service experience of the reliability of the SM150D19 contactors, meant that the effect of the failure of the 95PA or 96PA was not considered a significant risk at the time.

It is likely the 95PA contactor on EI-GPN had a dormant anomaly, which was perhaps a less tightly assembled pin and plunger. As this was now under increased use, it started to slide out of position. It eventually reached the point where the contactor plate between terminals A1 and A2 could no longer make proper contact. The presence of arcing on the contact terminals suggests the slippage was gradual and took place over a number of cycles. The total number of cycles this contactor had carried out at the time of failure is unknown.

However, this did not affect the de-energised condition whereby the internal spring takes over and the contact plate between terminals B2 and B3 was re-established. Therefore, the DC power distribution system returns to normal with systems properly powered when the TRU was selected OFF. This is what happened when the aircraft commander deselected the TRU thereby deenergised the 95PA contactor and returning power to the affected aircraft systems.

Flight crew decision making surrounding the TRU

Having previously queried operating with the TRU ON, the commander appeared conscious of how it affected the applicability of the QRH procedure during the first flight. In those circumstances, the QRH procedure required the crew to keep the TRU ON and arrange maintenance action on arrival. With no persisting fault after arriving at Leeds, the commander – in liaison with the operator's engineering department – took the practical decision of returning the aircraft to Belfast where company engineers could inspect it.

During the incident, with the QRH checklist still in his mind, the commander selected TRU OFF, attempting to resolve the failure by returning the aircraft to what he termed its "original design" (in reference to its electrical configuration prior to OEB 56).

Effects of the failure

Significance

Some anomalies existed between the manufacturer's simulator session and the flight crews' recollection of the event – for example, EFCP and engine instrumentation functionality – but the overall significance of the failure was similar. The manufacturer and the operator recognised the challenging nature of the 95PA contactor failure, which caused unforeseen and significant problems with major systems. This included its effect on, instrumentation, primary and secondary flying controls, landing gear, autoflight, engines, communications, navigation, and operational procedure access for flight crew.

Startle and surprise

The CVR and information from the flight crew indicated supportive teamworking during the event between crew members. The sudden magnitude of the failure caused a degree of natural startle and surprise, which characteristically affected aspects of their communication and information processing. Accordingly, their experience provides opportunity to explore startle management.

The ambiguous nature, and unclear source, of the technical symptoms caused persisting stress and surprise while the flight crew attempted to re-evaluate the situation. Information from both pilots alluded to the disorientating effects of flight instrumentation and EWD abnormalities. Being apparently unable to access electronic procedures removed part of their habitual rule-based response, which could have helped them to recover from the effects of startle and surprise.

The dynamic nature of the incident perpetuated the surprise, probably raising any potential for plan continuation bias, as the crew commenced then continued with the approach while focussing on the salient features of the failure but without some systems necessary for landing. The commander had experienced electrical smoke during previous simulator sessions which possibly exacerbated a 'fight or flight' response. He described feeling time pressured and focussed on, what could be considered, the active solutions of landing the aircraft and resolving the technical failure. Continuing the approach without the landing gear and flaps deploying, the pressure on the commander continually increased. He perceived there was insufficient time to use landing gear gravity extension while also feeling concern over already difficult pitch control forces worsening during a go-around manoeuvre. Consequently, he intuitively turned off the TRU at around 1,900 ft amsl, fortunately restoring lost systems. Some plan continuation bias might have persisted while the flight crew attempted to achieve approach stabilisation, which occurred around 500 ft agl. That was somewhat below the operator's revised stabilisation height of 1,000ft but coincident with its previously specified figure.

Situation management

As part of the manufacturer's safety action, an abnormal procedure has been included in OEB 56 Issue 3, which its simulator pilots used to demonstrate resolving the incident failure. That particular procedure was unavailable to the incident crew leaving them with no clear course of action. While recognising the challenging nature of that situation, the manufacturer recommended pilots consider taking time to complete any outstanding procedures before flying an approach. Relevant QRH procedures during the incident would probably have resulted in the TRU being selected OFF. Otherwise, standby pitch trim and ADC switching were functioning, and the *'Landing gear gravity extension'* and *'Reduced flaps landing'* procedures were available. Such rule-based responses alleviating any startle and surprise. Notwithstanding any need to refer to offside instruments, giving control of the aircraft to the co-pilot could reduce the commander's physical and cognitive workload, assisting with rebuilding situation awareness for completing any briefing and decision-making processes.

EI-GPN's crew intuitively, though successfully, resolved the startling and complex failure whilst flying the approach. However, given that pressure on them had been rising as the approach continued, making time to regain situation awareness might have weakened the fight or flight response, and revealed other options ahead of reaching a stage where an intuitive response became necessary.

As well as being used to prioritise tasks, situation management tools like *'Fly, navigate and communicate'* and *'Plane, path and people'* can help crew update their situation awareness, and manage startle and surprise. Performing a simple, linear rule together can help crews structure their analysis, manage workload, lower stress, and generate options for any subsequent decision-making process. Possibly suited to EI-GPN's unforeseen failure, where certain normal cues were removed and there was no clear course of action. Such processes can preclude plan continuation bias if alternative options include delaying commencing an approach to troubleshoot a technical failure, complete checklists and configure the aircraft; or discontinuing an approach after resolving a failure to rebuild situation awareness, particularly if stability criteria cannot be met.

Wishing to proactively assist its crew during potentially challenging circumstances, the operator stated its intent to adopt a rule-based structure for situation management, helping crew to manage startle and rebuild situation awareness.

Conclusion

The aircraft was operating under EASA Emergency Airworthiness Directive E-AD 2021-0120-E which had been introduced to de-risk potential problems within the battery master toggle switch and the 1PA contactor. This meant that the TRU was selected ON and the 95PA and 96PA contactors were energised throughout all flights.

In this case the 95PA contactor failed when the TRU was selected ON and thereby not properly energising, disconnecting the DC output from the TRU to the STBY and EMER BUS bars. This caused a number of vital aircraft systems to drop off-line during the aircraft's approach to Belfast City Airport.

The extreme, unforeseen, and dynamic nature of the failure caused characteristic startle and surprise effects in the flight crew. Without a specified procedure to follow, they continued flying the approach, successfully restoring systems by turning off the TRU which restored electrical power to the affected systems by de-energising failed relay 95PA.

The effect of a malfunction of the 95PA or the 96PA contactor when the AD was issued may not have been fully understood, and so an in-flight rectification procedure had not been introduced into the QRH to allow the flight crew to identify, troubleshoot and restore systems. The report considers situation management methods for helping crew mitigate startle and rebuild situation awareness before completing an approach.

Technical cause of the contactor failure

The failure of this 95PA contactor fitted in EI-GPN was caused by a slippage between the plunger and pin assembly operating under increased cycles. The slippage resulted in poor connection, localised arcing and subsequent loss of continuity across its A1 and A2 terminals. A definitive cause of the pin and plunger slippage with the 95PA contactor fitted to EI-GPN and several other contactors manufactured during 2015, could not be fully determined.

Safety Actions

The aircraft manufacturer has been fully engaged in the investigation and has taken several safety actions. They have carried out additional research to understand the effect of the failure of the 95PA and 96PA contactors on the aircraft systems and the combination of malfunctions the pilots may experience and what action they should take in-flight. They have taken the following safety actions:

ATR have published Airworthiness Operator Messages (AOM 2021/05 issues 4 to 5) to give advice and direction to operators on the actions to be taken should non-normal TRU events occur whilst operating under AD 2021-0120-E. In particular Issue 5, which provided operators with Operations Engineering Bulletin (OEB) 56/3. This OEB made recommendations to operators on mitigating actions to be taken in the event of the temporary loss of all cockpit display systems and recommendations in case of electrical failure during the flight while the TRU is ON.

They have also addressed the technical issues that required the introduction of the AD 2021-0120-E by taking the following safety action.

An AOM 2021/05 issue 6 was issued on 7 March 2023 to publish Service Bulletins ATR42-24-0062 and ATR72-24-1032. These SB introduce a modification to the battery toggle switch (FIN 7PA) circuit integration. As per EASA AD 2023-0078R1 published on 20 April 2023, the embodiment of these SB removes the requirement to operate with TRU ON.

The operator stated its intent to maximise learning from this incident, adopting a rule-based structure to proactively assist crews with managing startle and rebuilding situation awareness.

Published: 22 February 2024.

Accident

Aircraft Type and Registration:	Extra NG, G-MIIL	
No & Type of Engines:	1 Lycoming AEIO-580-B1A piston engine	
Year of Manufacture:	2021 (Serial no: NG028)	
Date & Time (UTC):	2 April 2022 at 1059 hrs	
Location:	Upper Heyford, Oxfordshire	
Type of Flight:	Private	
Persons on Board:	Crew – 1	Passengers – None
Injuries:	Crew – 1 (Serious)	Passengers – N/A
Nature of Damage:	Aircraft destroyed	
Commander's Licence:	Private pilot's licence	
Commander's Age:	62 years	
Commander's Flying Experience:	593 hours (of which 28 were on type) Last 90 days – 7 hours Last 28 days – 4 hours	
Information Source:	AAIB Field Investigation	

Synopsis

Whilst the aircraft was in straight and level flight at 184 KIAS, the canopy broke up without warning. The pilot, the only occupant of the aircraft, sustained serious injuries and was unable to continue flying the aircraft. He was wearing a parachute and bailed out, the aircraft entering a descent and colliding with an unoccupied block of flats.

The investigation identified a lack of appropriate bonding between the inner and outer canopy frame around the front of the canopy. This caused localised and increased stresses within the transparency which under flight loads promoted fatigue crack development. When these cracks reached a critical length, catastrophic failure resulted.

One Safety Action has been taken by the aircraft manufacturer and two Safety Recommendations are made regarding the design and installation of the canopy.

History of the flight

The pilot had planned to undertake a local flight to conduct some aerobatics and arrived at Bicester Airfield at approximately 1015 hrs on the morning of the accident. The weather was good with only light winds and some cloud at about 6,000 ft. He towed the aircraft out of the hangar where it was kept and performed a daily check, with no defects being identified. The aircraft had been refuelled after the previous flight and, having completed the external checks, the pilot put on a parachute before climbing into the rear seat of the cockpit. He secured his harness and closed the canopy, before completing the pre-start checks and starting the engine. The pilot then taxied to the holding point for Runway 06, where he performed the engine power checks, before taking off and departing west towards Upper Heyford.

After takeoff, the pilot began to climb to 2,000 ft amsl and was instructed by Oxford Radar ATC to hold to the east of the extended centreline of Oxford Airport Runway 01 to remain clear of a departing aircraft. A few minutes later the pilot was cleared to continue his flight to the west. On reaching the vicinity of Enstone Airfield, the pilot climbed to around 6,000 ft amsl and spent about eight minutes conducting aerobatics. He reported that the manoeuvres included rolls, half-cubans, and stall turns. Having completed the aerobatics, the pilot commenced his flight back towards Bicester at a height of about 2,200 ft amsl.

The pilot described that a few minutes later, and with the aircraft flying straight and level, the canopy suddenly "exploded" around him. He lost his glasses and experienced severe wind blast to his face, the combination of which left him unable to see properly. He also lost his headset. He managed to maintain control of the aircraft and continued flying for just over 20 seconds, trying to understand what had happened and what his options were.

The pilot only had sufficient vision to make out the shape of the instrument panel in front of him. Realising he was unable to see sufficiently to be able to either continue flying back to the airfield or land safely he decided he had no option but to bail out of the aircraft. He undid his harness and stood up, the wind pulling him out of the aircraft. The aircraft then banked to the left and descended to the ground, colliding with a newly constructed, but unoccupied, three-storey block of flats. No one on the ground was injured.

Once clear of the aircraft, the pilot pulled the ripcord on his parachute, which quickly opened, allowing him to drift down to the ground. He landed in a playing field close to the village of Upper Heyford where members of the public attended to him and alerted the emergency services. The emergency services were quickly on the scene, including an air ambulance which transferred the pilot to hospital. The pilot had sustained a deep laceration across the right side of his face, resulting in the loss of sight in his right eye.

Accident site

Main accident site

The aircraft hit the ground approximately 1 m from an unoccupied newly built block of flats. Marks on the ground and on the building show the aircraft was at a shallow angle at impact with enough energy to continue to penetrate the building. The engine embedded itself into the foundations of the building and was lodged beneath the ground floor concrete beams. The outer walls and a window of two adjacent flats had collapsed inwards. The aircraft had disintegrated to the extent that the only recognisable parts were the tailplane and fin. Marks on the brickwork left by the leading edges of the tailplane and fin indicated the trajectory of the aircraft at impact (Figure 1).

Figure 1
Accident site showing marks on the walls made by the fin and tailplane

The scale of the damage to the aircraft meant the pre-impact integrity of the flying controls or any of the aircraft systems could not be established. However, the aircraft's Electronic Flight Instrument System (EFIS)[1] was identified and its solid-state memory card was recovered for analysis.

During the examination of the remains of the aircraft it became apparent that the aircraft's emergency locator transmitter (ELT) had automatically activated.

The aircraft's canopy assembly was absent from the main accident site with the exception of a section of frame from the right side with the rear hinge bracket attached (Figure 2).

Footnote

[1] Garmin manufactured G1000.

Figure 2
Right rear section of canopy frame and hinge

Canopy site

Analysis of the data on the EFIS memory card assisted in identifying an area approximately 3 km from the main accident site where canopy parts were subsequently located (Figure 3). They were strewn over an area of approximately 300 m by 200 m consisting of fields and a small wood. The canopy and frame were fragmented, and the widespread distribution indicated that the canopy had broken up before hitting the ground. An extensive search resulted in approximately 75% of the canopy being recovered.

The transparency was broken into shards varying in size, the smallest being approximately 7 cm^2 and the largest approximately 500 cm^2. Significant parts of the frame were also recovered, including those that made up the entire left side with the shoot bolts, linkage tube, its spring and the front and rear cockpit handle assemblies.

Recorded information

The EFIS memory card contained a recording of the accident flight and previous flights since July 2021. Parameters were recorded once per second and included GPS derived position, airspeed, groundspeed, pitch and roll attitude, vertical and lateral acceleration, and engine speed. The recording of the accident flight commenced at 1031 hrs when the aircraft was on the ground at Bicester Airfield and ended at 1058:34 hrs.

A CCTV camera positioned 500 m from the accident site captured several images of the aircraft shortly before it struck the ground. Radio communications between the pilot and Oxford Radar ATC were also available.

Summary of recorded data

The aircraft took off from Runway 06 at Bicester Airfield at 1037 hrs before heading west and climbing to 5,500 ft amsl. Whilst the aircraft was holding at the request of ATC, its recorded load factor during this period varied from between 2.5 g and 0.7 g. G-MIIL then proceeded to the vicinity of Enstone Airfield where a series of aerobatic manoeuvres were flown for about eight minutes, at altitudes between 5,300 ft and 7,300 ft amsl.

At 1055 hrs, the aircraft started to head back towards Bicester, which was 12.5 nm to the east. The EFIS calculated wind direction and speed were 040° at 14 kt. When the aircraft was about 1 nm west of Upper Heyford, it started to slowly descend from 2,200 ft amsl with the engine speed stabilised at 2,400 rpm. Shortly after at 1057:59 hrs, as the aircraft was descending through 1,900 ft amsl (1,600 ft agl) at an airspeed of 184 KIAS (a groundspeed of 173 kt), it suddenly pitched up from 0° to 10° whilst also rolling from a wings level attitude to 20° right bank.

During the next 23 seconds, the aircraft's pitch and roll varied erratically, and it also briefly climbed to 2,000 ft amsl before starting to descend again. During this period, the engine speed varied between 2,380 and 2,410 rpm. The erratic pitch and roll movements then stopped, and the engine speed stabilised at 2,400 rpm with the aircraft at 1,700 ft amsl (1,300 ft agl). It then progressively pitched nose down whilst also rolling left, and its rate of descent increased. The recorded accelerations appeared normal as the aircraft continued its descent, with no evidence of airframe vibration.

The last EFIS data point was recorded at 1058:34 hrs, when the aircraft was at a height of about 250 ft agl. The airspeed and groundspeed were 198 KIAS and 171 kt respectively, it was descending at nearly 7,000 ft/min and was in a left bank of 37°, with a nose down attitude of 19°. This was consistent with the CCTV images.

Position of canopy separation

The position where the sections of the canopy were found, in combination with the aircraft's flightpath, wind direction and speed, indicated that the canopy had most likely separated from the aircraft at about 1057:59 hrs. At this time, the aircraft was at an altitude of 1,900 ft amsl (1,600 ft agl) and its airspeed was 184 KIAS (Figure 3). This also coincided with the start of erratic changes in both pitch and roll.

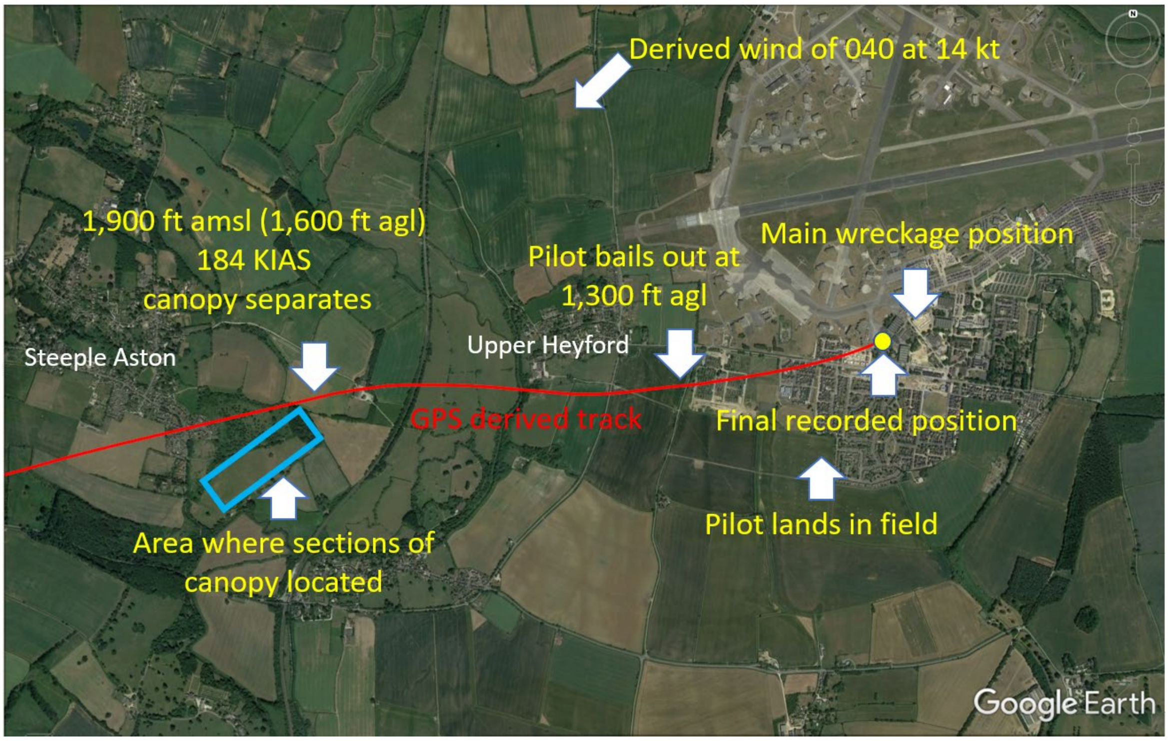

Figure 3

Aircraft track and probable position of canopy separation

Maximum aircraft loads and airspeed

Accident flight

During the first aerobatic manoeuvre, the load initially increased to 2 g, before reducing to -0.15 g. Subsequent manoeuvres were similar, with initial positive loads followed by negative loads recorded. A maximum load of 3.8 g and a minimum of -1.2 g was recorded. The final manoeuvre ended with a positive load of 3.6 g.

The maximum airspeed recorded during the entire flight was 192 KIAS. This occurred during the period when the aircraft had been performing aerobatic manoeuvres.

Previous flights

A review of the recorded flights showed that V_{NE} (221 KIAS) had been exceeded during four previous flights. These had all occurred in July 2021 and had been flown from the airfield adjacent to the aircraft manufacturer's facility. The maximum airspeeds during these flights were 227, 242, 249 and 253 KIAS. The maximum recorded load had also occurred during one of these previous flights, with a normal and lateral load of 5.9 g and 0.89 g respectively.

Survivability

The pilot had been wearing a National 425 parachute. He had previously owned an Extra 300L but reported that he had not normally worn a parachute when flying this type as the cockpit was smaller and he found doing so uncomfortable. He commented that in the

Extra NG the parachute, which was worn on his back, provided a better seating position in the somewhat larger cockpit. He therefore always wore it whilst flying. This improved seating position whilst wearing a parachute on the back had been reported by another Extra NG pilot questioned by the AAIB.

The pilot did not wear a helmet. He wore an in-ear headset which he found remained in place better whilst conducting aerobatics than the traditional over-head style of headset.

The pilot was required to wear glasses whilst flying.

Aircraft information

The Extra NG is an all composite, fully aerobatic, two seat aircraft and is certified with a load factor of -10g to +10g. The type was first certified by EASA in October 2019 to Certification Standard 23 (CS23) under the Level 1 low speed category, covering aircraft with seating for 0-1 passengers and a V_{NO} less than or equal to 250 knots. Under this standard, the aircraft structure must be designed to withstand the operational parameters that affect structural loads, strength, durability, and aeroelasticity.

The engine drives a three-blade variable pitch propeller. The cockpit is fitted with a Garmin G1000 EFIS with a data recording capability. The aircraft is designed to be flown from the rear seat although it is fitted with dual controls and simplified instrumentation in the front cockpit.

G-MIIL (Figure 4) was manufactured in 2021 and registered in the UK in August of that year and prior to the accident had accrued approximately 40 flying hours. Its Certificate of Airworthiness was due to expire on 14 September 2022.

Figure 4
Photograph of G-MIIL

Canopy

The canopy consists of a single piece tear drop transparency bonded within a composite frame. The canopy generates lift in flight. The canopy frame is attached to the fuselage with three steel hinge pins and brackets on the right side of the cockpit. The canopy opens to the right and is restrained in the fully open position by a flat woven nylon lanyard (Figure 8).

The canopy frame is constructed from carbon fibre prepreg[2] EP121-C20-45, laid up to form an inner U-shaped channel and an outer skin. The inner frame channel varies in its cross-sectional shape to comply with the aerodynamic contour required to match the shape of the cockpit rim. The area where the outer and inner skin are bonded together, are prepared using the peel ply[3] technique. The outer skin is bonded to the inner frame using Loctite® EA 9395, a two-part epoxy adhesive.

The canopy hinges, shoot bolt mechanism and its guides are fitted before the outer skin is bonded to the inner frame.

The canopy transparency is made from a single sheet of poly-methyl methacrylate (PMMA) moulded into the required shape. Its moulding method and the shape of the canopy required in the Extra NG mean that the PMMA is thinner in section at the front area of the canopy and progressively thicker at the rear of the canopy. Its cross-sectional thickness varied on G-MIIL between 2.9 mm at the front to 3.5 mm at the rear.

The transparency is bonded into the canopy frame using a urethane adhesive compound. The canopy frame is finished using an epoxy primer filler, basecoat, topcoat and high gloss clear coat. In this case the frame was in a metallic silver.

There is a small sliding window fitted on the left side of the canopy transparency. It is positioned for ease of operation by the pilot in the rear seat and slides rearwards to open. The canopy is also fitted with a rubber seal around the base of the frame. This is to reduce drafts and the ingress of water.

Canopy locking mechanism

The canopy is locked in the closed position by three steel shoot bolts which engage in roller lugs attached to the fuselage, spaced along the left edge of the cockpit wall. The end of the shoot bolts is a ramp design which creates a mechanical advantage to assist the mechanism in compressing the weather seal when closing and locking the canopy. The ramp is 15 mm in length and has a rise of 5 mm. When this engages with the rollers as they travel along the ramp the mechanical advantage is 3 to 1.

Footnote

[2] Prepreg. Woven carbon fibre matting or matrix in which the fibres have been pre-impregnated with an epoxy resin in a partially cured state. The material is shaped and formed in a mould to achieve the desired shape and placed in an autoclave to complete the curing process.

[3] Peel ply. A layer of synthetic fabric material is laid on the outer surface of the carbon fibre during fabrication. It absorbs some of the matrix resin and becomes part of the matrix surface during the curing process. Prior to assembly the carbon fibre components, when removed from each surface leave a clean but slightly roughened surface on the matrix to provide a ‘key’ for the epoxy bonding compound.

The shoot bolts are operated by two sets of identical handles, one set situated in the front and one in the rear of the cockpit. The three shoot bolts are attached to a linkage tube which is held in the locked position by a tension spring. The shoot bolts are engaged in their lugs using a sliding lock and release handle which protrudes through the canopy frame. The sliding handle is operated by squeezing it towards a fixed handle until it is in the UNLOCK position. When released, with either the canopy open or correctly locked shut, the distance between centres of both handles is 70 mm.

With the canopy closed and the handle released, the handle will travel under spring pressure towards the locked position, stopping just as it enters the green LOCK area. This is a partially locked condition and the distance between the handle centres in this condition is 60 mm (Figure 5).

Figure 5

Canopy handle partly locked position when under spring pressure alone

To fully lock the canopy the handle must then be manually pulled rearwards into the fully locked position (Figure 6).

Figure 6

Shoot bolt handles (canopy in the closed and locked position)

It was observed that whilst operating the handle to the fully locked position on another Extra NG, it required a positive movement and resulted in a distinct 'clunk', which could be both felt and heard as it went into the fully locked position.

Figure 7 shows the extent of the shoot bolt engagement within the latch when the handles are in the fully locked and partially locked condition. The photographs were taken without the canopy outer frame skin in position. In normal circumstances these components are completely hidden from view.

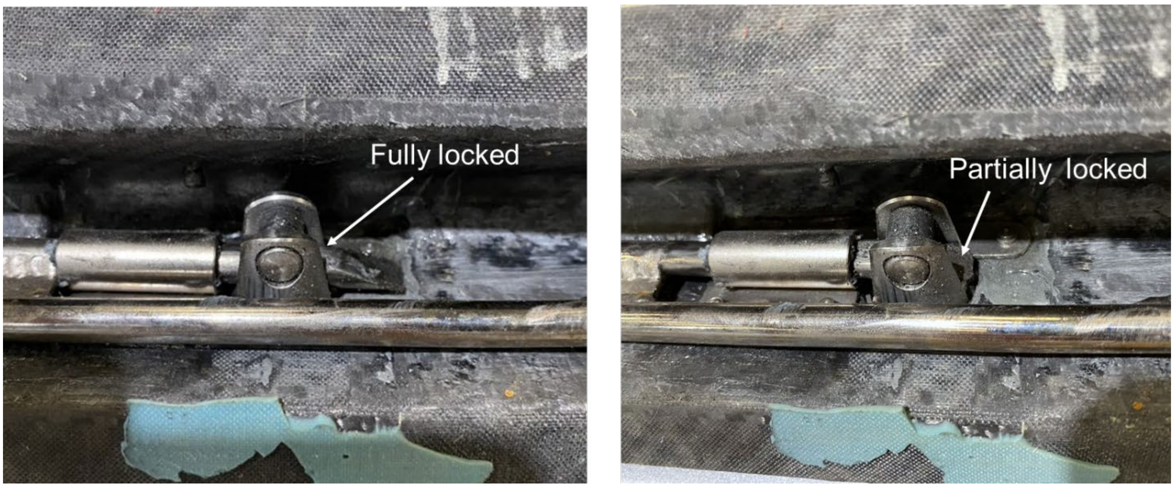

Figure 7
Shoot bolt and latch engagement conditions

Canopy normal operating procedure

The Pilot's Operating Handbook (POH) extant at the time of the accident described the canopy closing procedure (Section 7.7 Canopy) as follows:

> *'To lock canopy:*
>
> *Pull together the interior locking handles.*
>
> *Close the canopy. Verify the canopy reaches the locked position.*
>
> *Release the locking handles. Verify aft handle reaches the locked position.'*

The POH provided the following information on opening the canopy from the inside under normal situations:

> *'Pull together the interior locking handles of the front or rear seat and lift canopy to the right,*
>
> *The canopy strap will limit the opening angle.'*

The POH also described the canopy emergency opening procedure (Section 7.7 Canopy).

> *'Canopy emergency operating procedure*
>
> *Generally the emergency operation is equal to the normal procedure. When opening the canopy in normal flight the low pressure over the canopy will flip the canopy fully open immediately. However complete jettison of the canopy is also possible. In this case the canopy can be finally unlatched at its RH [right hand] hinge line by the following action:*
>
> *Push canopy slightly forward while opening.'*

The manufacturer stated that in the event of an emergency opening of the canopy in flight, the forces involved would be sufficient to break the retaining lanyard and that the canopy will break on hitting the upper wing surface. It was considered that the broken canopy would then fall away to the rear of the aircraft in the airflow.

Canopy partially locked condition

During the investigation the possibility of a partially locked canopy condition occurring was discussed with the manufacturer. As a result, the manufacturer reviewed the POH and published revision Extra NG 1.11 20221223, dated 23 December 2022. This introduced a schematic diagram and amended the locking instructions as follows:

> *'To lock the canopy:*
>
> *Pull together the interior locking handles.*
>
> *Close the canopy. Verify the canopy reaches the closed position.*
>
> *Release locking handles.*
>
> *Pull the aft locking handle fully rearward to the end stop. Verify handle is in the LOCK position (green marking).'*

Further discussion considered the effect of flying an aircraft with the canopy in the partially locked condition. The manufacturer considered that in straight and level flight aerodynamic forces impart a tensile load on the canopy hinges, shoot bolts and associated lugs. However, during increased positive g loads, such as experienced during aerobatics, the tensile load on the canopy hinges and lugs would be reduced and would compress the canopy against its weather seal. When this happens the shoot bolt spring would tend to move the shoot bolts towards their fully engaged position.

Service Bulletin (SB) NG-2-22

As a result of examination of the remains of the canopy from G-MIIL, the manufacturer introduced SB NG-2-22 in December 2022. This was non-mandatory so compliance was only recommended. The SB applied to Extra NG aircraft, Serial Numbers NG001 to NG038, which included G-MIIL (serial number NG028) and SP-HMM (serial number NG026).

The SB stated that its purpose was:

> *'An improvement of the bonding between the inner and outer canopy frame shall be introduced. Although there is currently no reason to assume that the canopy of the aircraft requires any technical modifications, as a mere precautionary measure the carbon fibre canopy frame shall be further improved and strengthened by reworking of the adhesive glue bonding between the inner and outer canopy frame'.*

The SB required the injection of bonding foam into the void between the inner and outer canopy frame at the front of the canopy from the front hinge on the right side around to the front shoot bolt on the left side of the canopy.

Canopy modification

In June 2022 and prior to the issue of the issue of SB NG-2-22, the improvements that later were introduced by the SB were embodied on an aircraft that had been returned to the manufacturer by its owner to rectify an unrelated issue. Its owner was informed of the installation but when collecting his aircraft, no documentation was provided to certify that this activity was carried out.

Aircraft examination

Aircraft structure

Despite the extensive damage to the aircraft, an examination of the wreckage found that the aircraft was complete, except for its canopy, when it hit the building. It was not possible to fully determine the continuity of flying controls or serviceability of any of the aircraft systems, except those recorded by the EFIS.

No foreign objects, including bird remains, not associated with the aircraft, or the building it struck, were found in the wreckage.

Canopy structure

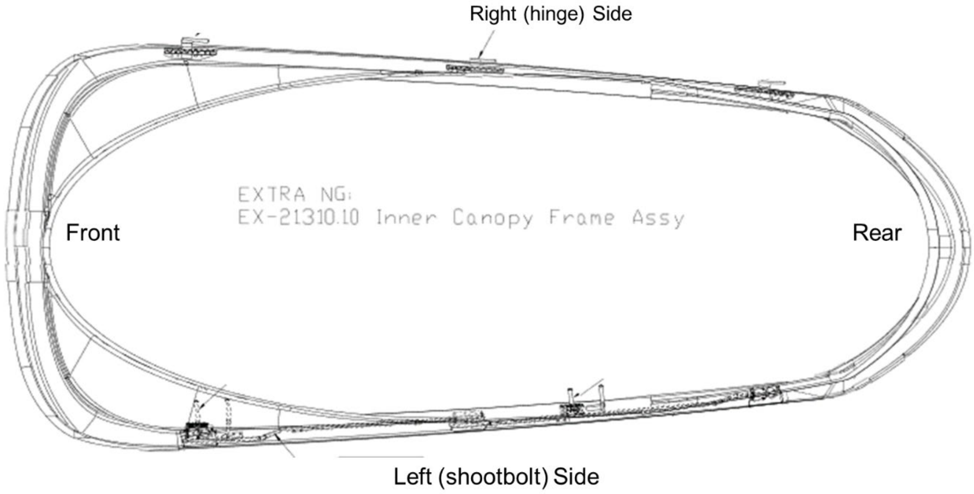

Figure 8

General arrangement of the canopy frame (courtesy of the manufacturer)

All the canopy parts were laid out and despite the extensive fragmentation showed that the left side of the canopy had fragmented into generally larger parts than the right (Figure 9).

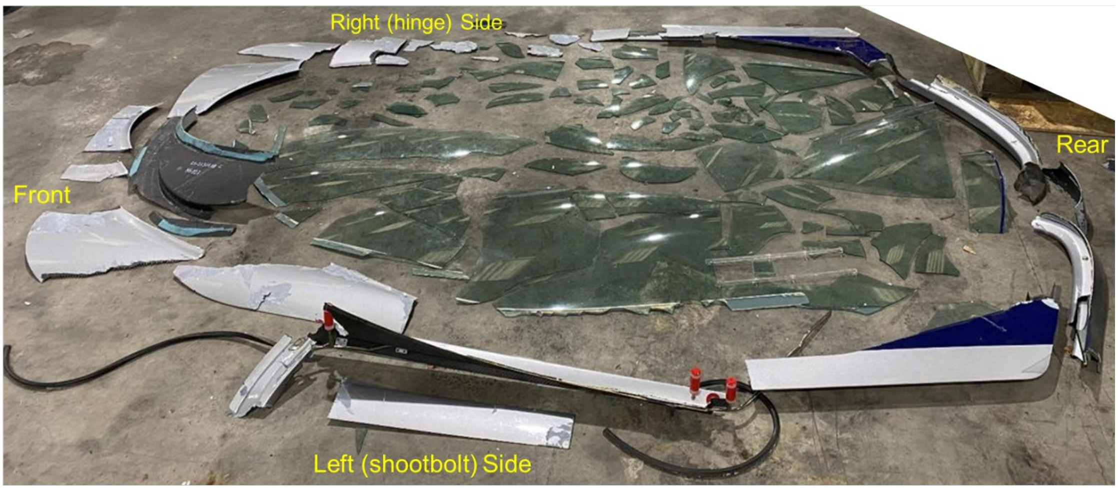

Figure 9

Canopy remains

All three fuselage mounted canopy lugs were found correctly attached to pieces of fuselage which made up the left edge of the cockpit. Two of the three fuselage mounted hinge brackets were also found attached to pieces of the fuselage from the right edge of the cockpit. Two hinge pins were found. One was from the rear hinge assembly, the position of the other could not be determined.

The restraining lanyard was found attached to the rear cockpit bulkhead. The unattached end of the lanyard was frayed and had been torn from the canopy frame bolt to which it was originally attached.

The rear section of the right of the canopy frame (Figure 2), still had its hinge pin attached to its bracket.

The left side of the canopy frame was severely damaged and distorted, but the shoot bolts, linkage tube and its handles were present. Despite the extensive damage the linkage tube and shoot bolts were being held in the closed and locked position by the spring (Figure 10). This part of the canopy had landed in a ploughed field. There was no evidence of soil or organic matter on any part of this structure indicating that the damage had occurred prior to it hitting the ground.

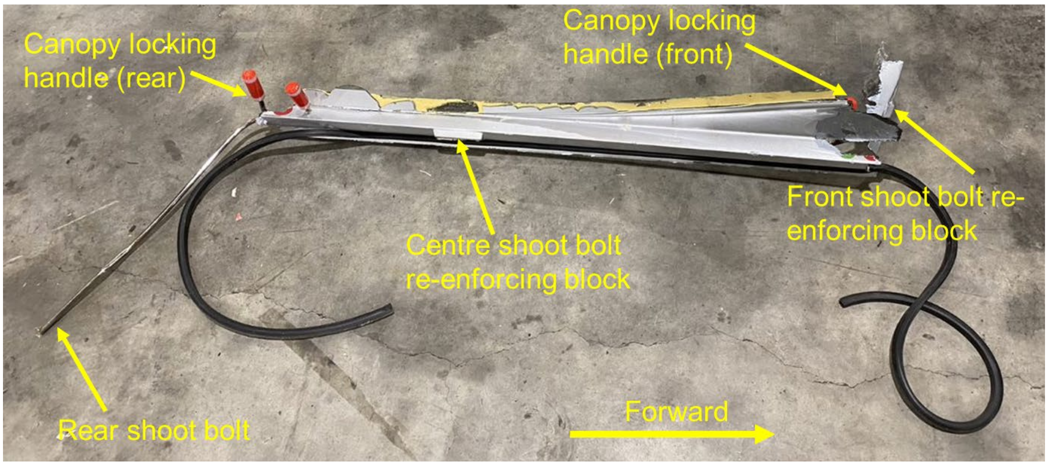

Figure 10

Left side canopy frame

The front shoot bolt tube showed evidence of having been forced away from the fuselage mounted lug and roller. The centre shoot bolt assembly and surrounding canopy frame was undamaged with the shoot bolt in its locked position (Figure 11).

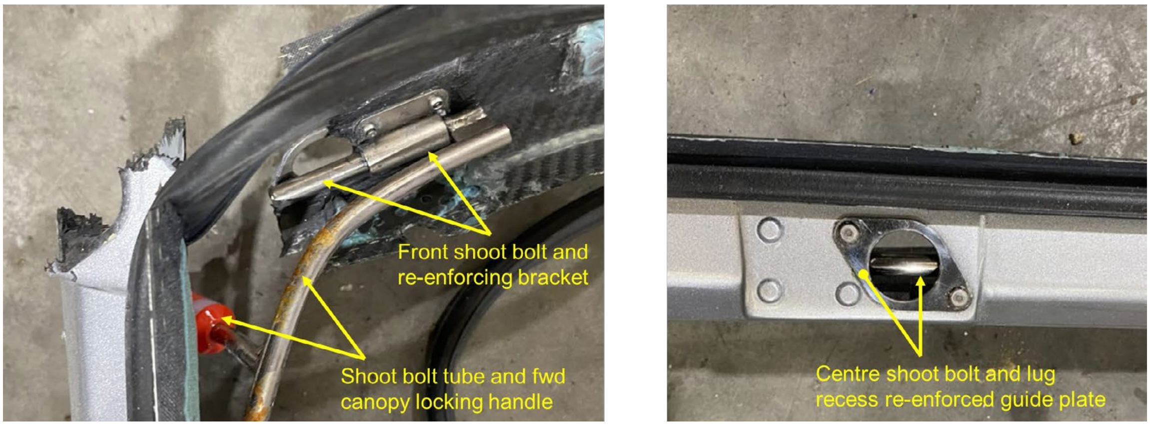

Figure 11

Front and centre shoot bolt assemblies

The rear shoot bolt was of a slightly different design to the two other shoot bolts as it was fitted into the end of the linkage tube on to which they were all attached. The canopy frame surrounding the rear shoot bolt had become detached. However, its re-enforcing plate and bracket were undamaged (Figure 12).

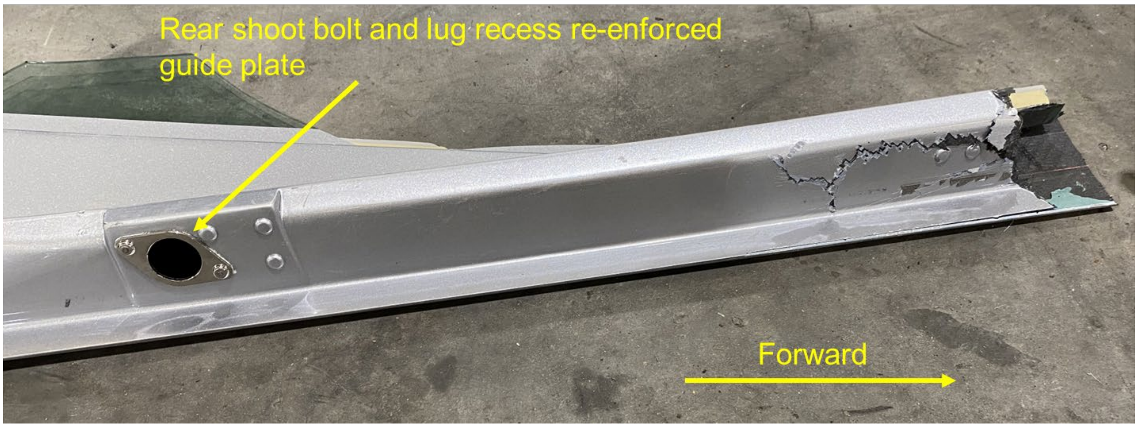

Figure 12
Left side rear canopy frame section

Front section of canopy frame

A schematic cross section of the front of the canopy frame assembly from the manufacturer's assembly diagram in this area is shown in Figure 13.

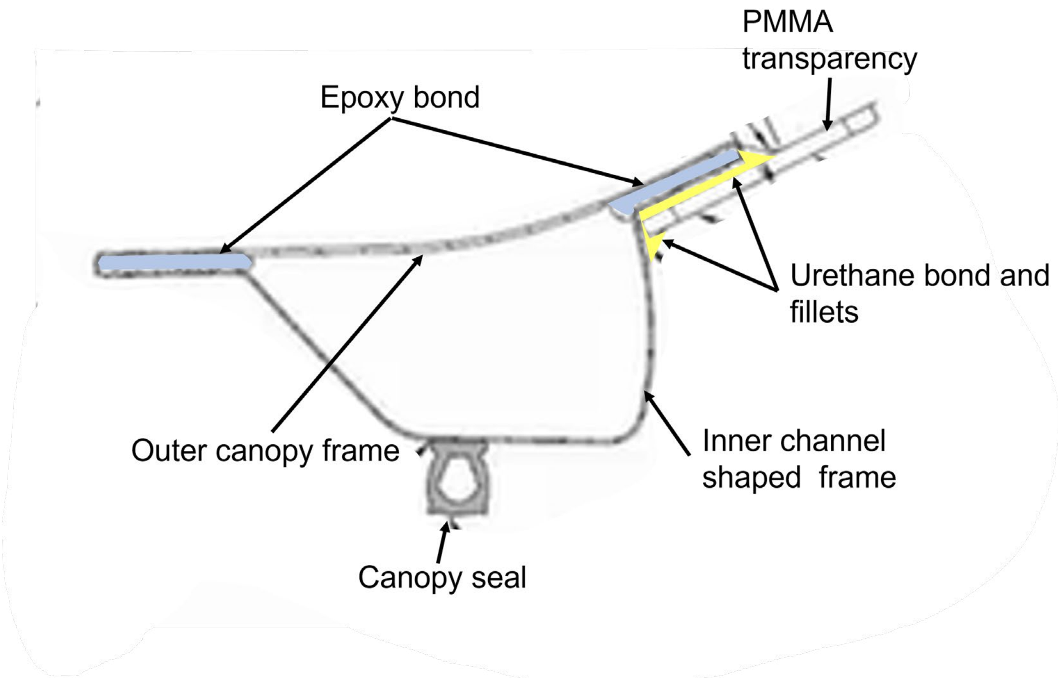

Figure 13
Schematic cross section of the front of the canopy frame assembly

Examination of the canopy frame parts revealed significant differences in the way the front area of the frame had broken up compared to the rear. The front parts had broken into small pieces (Figure 14). The outer skin had separated from the inner 'U' channel from the front lug to the front hinge.

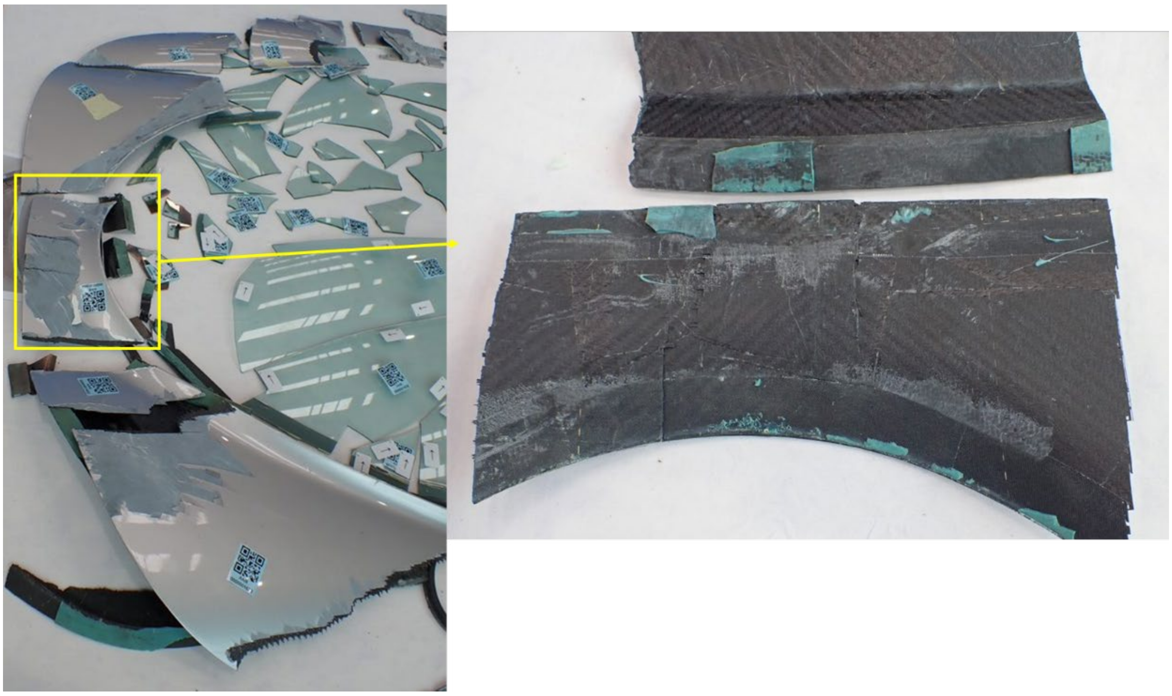

Figure 14
Canopy front section

Canopy Bonding

A bead of light blue coloured epoxy bonding material was present on the pieces of inner and outer frame in the areas that had come apart. In most cases, the bonding material was only present on one side of the mating face. In some areas the remaining bead of bond was sufficiently thin, that the peel ply area beneath its surface showed through.

One small section of the front canopy frame had a small area of bond which showed an apparent 'crystalline' feature and to be very thinly spread into the peel ply surface (Figure 15).

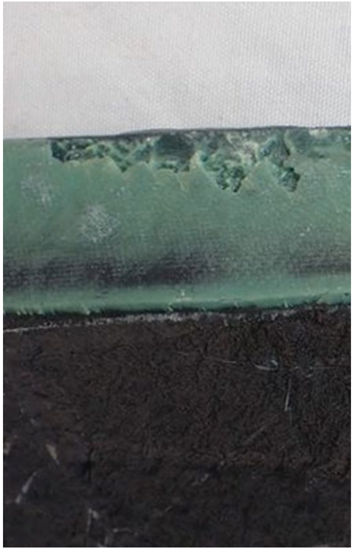

Figure 15
Epoxy bond 'crystalline' feature

Rear section of canopy frame

Parts of the rear canopy frame had breaks through the inner and outer skin. Other than small areas either side of the breaks, the remains of the inner and outer skin were still bonded together (Figure 16).

Figure 16
Part of the rear left side corner of the canopy frame

One area of the outer frame covering the shoot bolt mechanism had not been attached to the left channel of the canopy frame (Figure 17). The bead of bond material at the top of this piece of the structure was inconsistent and narrow and had not been fully applied over the peel ply area. In one small area, about 50 mm in length, it had not made contact with the inner frame at all (Figure 18).

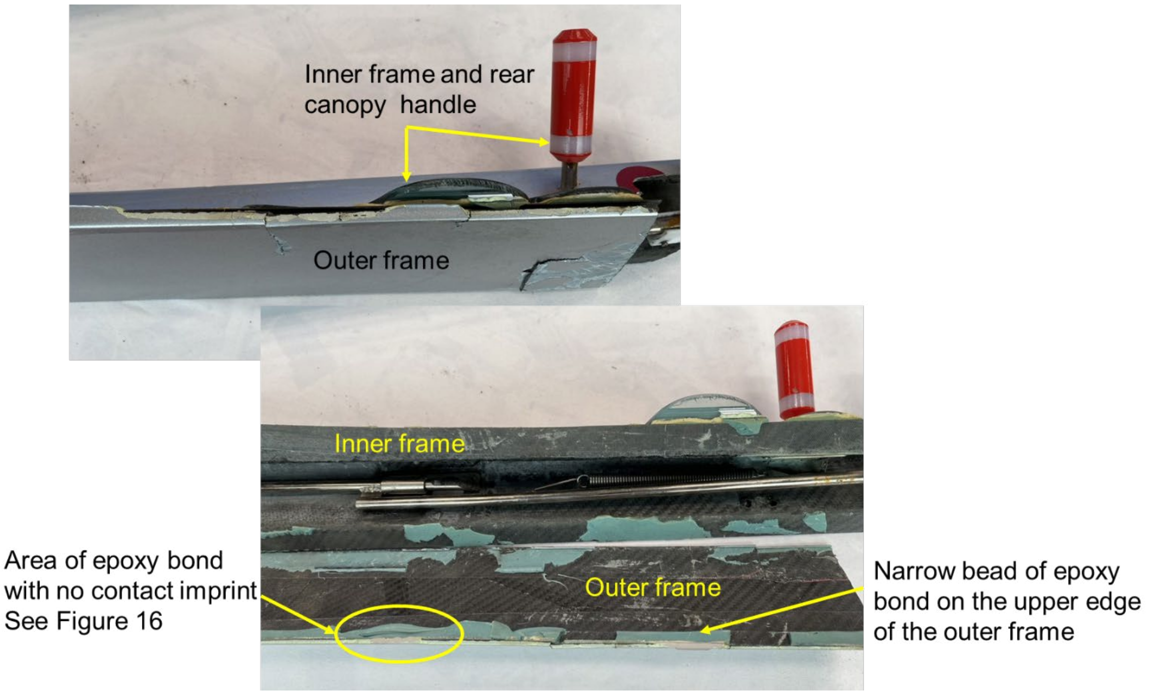

Figure 17

Canopy inner and outer frames left side

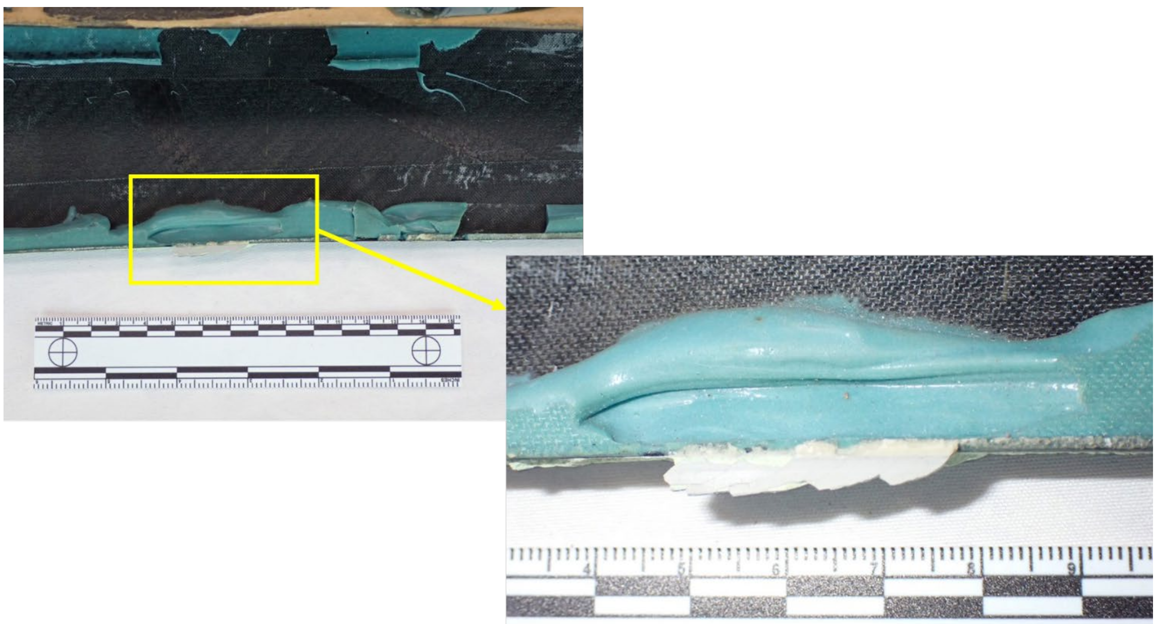

Figure 18

Area of epoxy bond showing there was no contact with the inner frame

A schematic cross section of this area of the frame showing the extent of the epoxy bond that should have been applied is at Figure 19. A schematic of the same section as found is shown in Figure 20.

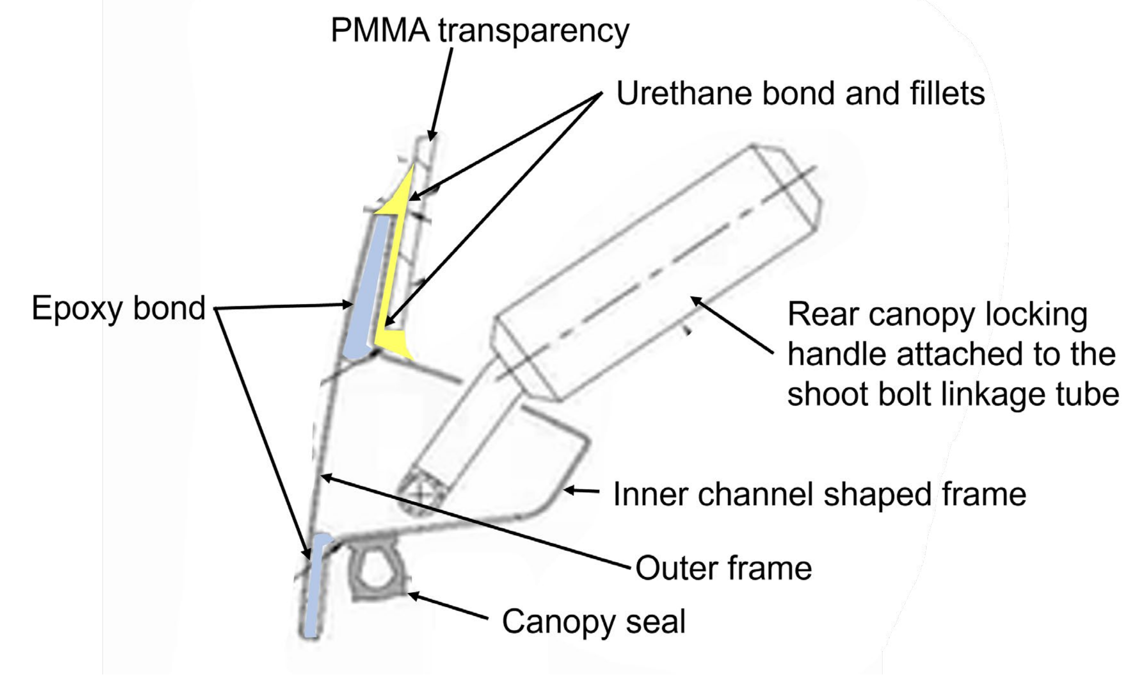

Figure 19

Manufacturer's canopy frame assembly schematic with the epoxy bond area highlighted (left side looking towards the front of the aircraft)

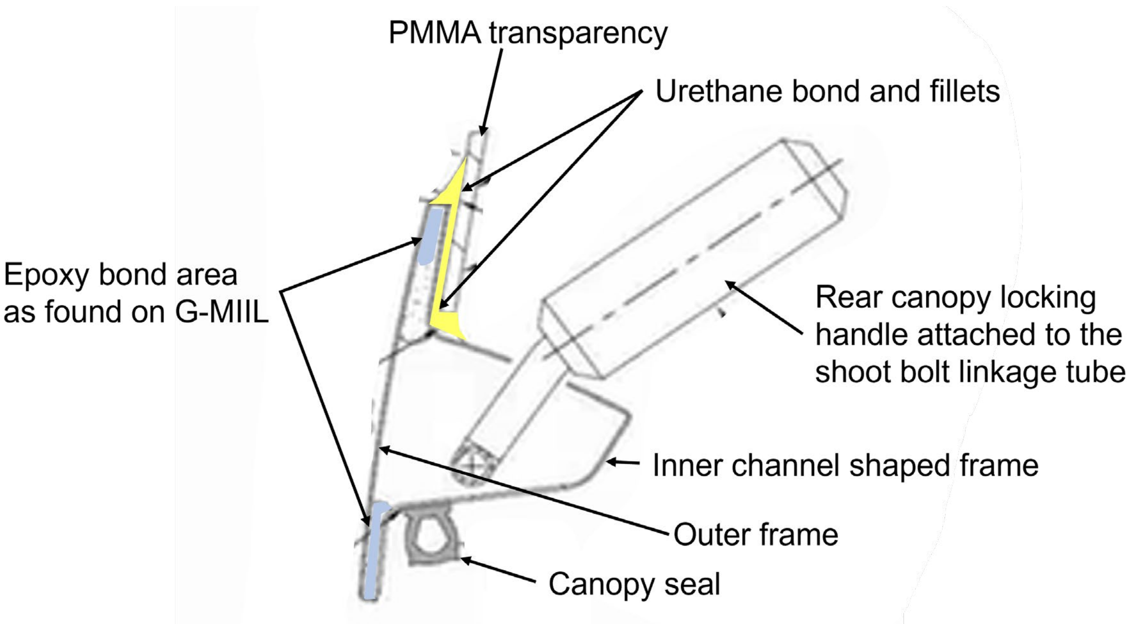

Figure 20

Epoxy bond area between the inner and outer canopy frames as found on G-MIIL

Unidentified hinge

Imprints left in the epoxy bond present on the surface of the hinge that was found completely detached, appears only to have been in contact with a peel ply surface on one of its faces. The other face showed only partial contact with a large area of the epoxy bond showing no peel ply area imprint (Figure 21).

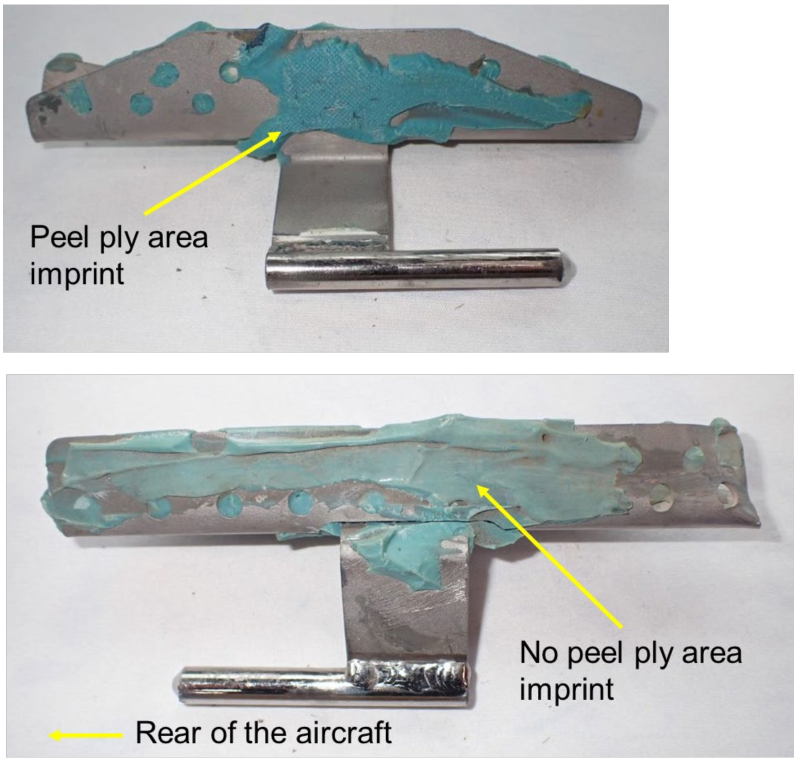

Figure 21

Both sides of unidentified canopy hinge showing the extent of the epoxy bond in contact with the peel ply area

Tests and research

Canopy locking mechanism

To establish the forces required to operate the canopy locking handles, measurements were taken on another Extra NG aircraft including:

- The force required to squeeze the shoot bolt handles together to open the canopy from the fully locked condition was 136 newtons.
- The force required to pull the handle from partially locked (under spring pressure only Figure 4) to the fully locked position was 60 newtons.
- The force required to squeeze the handles together from the partially locked position, to open the canopy was 90 newtons.

There were no observable visual differences between where the canopy frame and fuselage edges meet, when in the fully locked or partially locked condition.

Canopy structure

The AAIB engaged an independent body with composites and plastics structural expertise, to scientifically examine the remains of the canopy. The findings are below.

Fracture characteristics

The overall condition of the canopy frame showed that pieces at the front leading edge had very different fracture characteristics to the significantly larger parts from the rear. The rear parts showed overload, snapping and breakage through both the inner channel section and outer skin. In general, these outer skin and channel parts remained bonded together despite the overload breakages.

In contrast, the front pieces were much smaller and there were numerous areas where the inner frame had separated from the outer skin. The examination focused on the parts from the front of the canopy.

Canopy frame

Samples of the bonded areas, consisting of a blue coloured adhesive were examined by optical and scanning electron microscopy. The surfaces contained the imprint of a woven fabric. This was examined in detail to understand the nature of the bonded surface and evaluate the quality of the bond.

It was found that the surfaces on several sites were relatively clean with little matrix or resin present, showing an adhesive[4] failure at the interface. There was also significant porosity in some of the adhesive layer, which may be indicative of a problem with the bonding method. Figure 22 shows an example of this phenomena on one of the sample pieces. Numerous other pieces showed similar characteristics with apparent adhesion failure. There did not appear to be any areas which exhibited cohesion[5] failure.

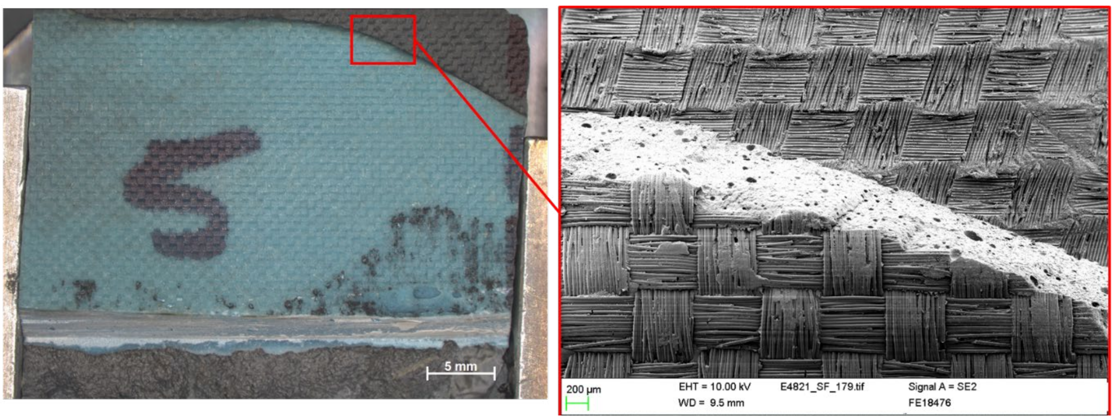

Figure 22

Resin bond adhesion failure and porosity

Footnote

4 Adhesion/adhesive failure occurs when the adhesive fails to robustly attach to the substrate appearing as if the adhesives separated cleanly from one of the bonded surfaces.

5 Cohesion failure occurs when the adhesive itself fractures or splits and adhesive is left attached to each substrate.

Canopy transparency

Parts of the transparency were also examined using the same method, particularly the edges where they had been bonded onto the canopy frame. Clear evidence of fatigue initiation was found. This resulted in crack initiation followed by fast, unstable crack propagation extending into the material. Figure 23 shows an example of this and Figure 24 shows its location.

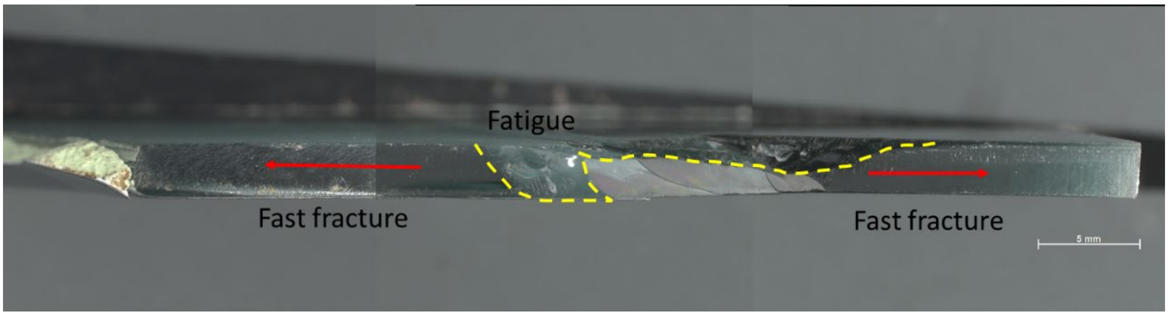

Figure 23

Evidence of fatigue and crack initiation

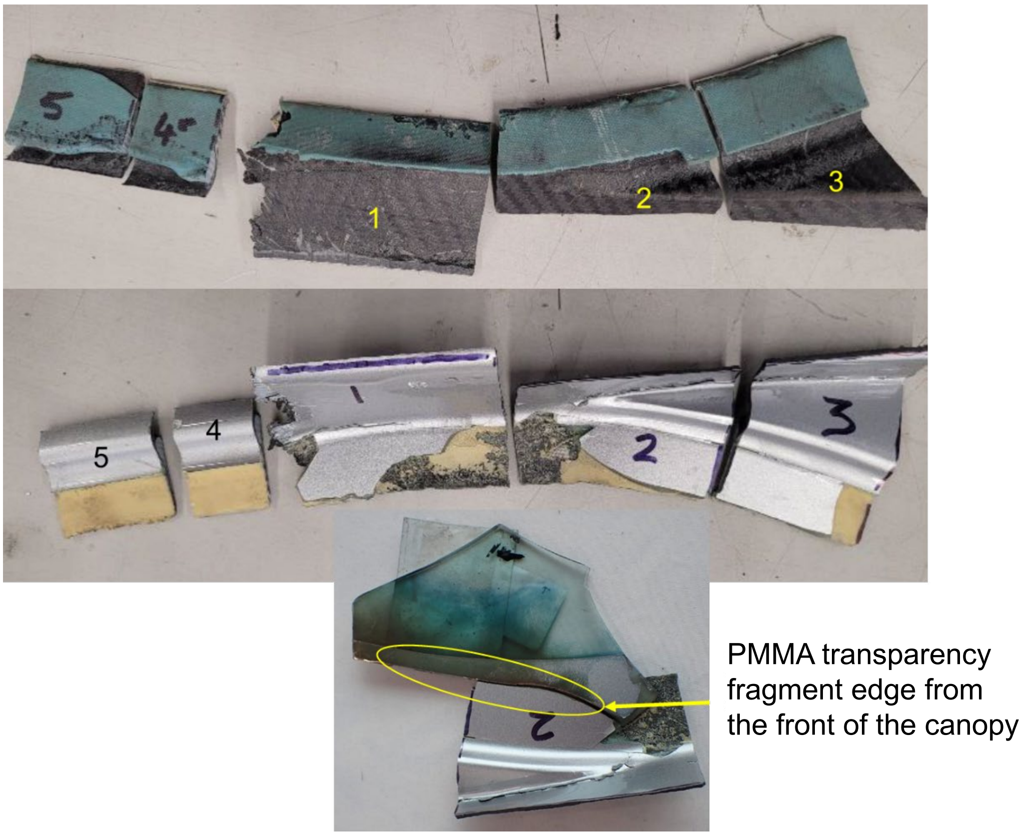

Figure 24

Parts of the inner frame from the front of the canopy (see also Figures 13, 14 and 15)

Fractures in this type of transparency material, when examined at high magnification, can show the direction of a crack propagation leading to fracture. Examination of the sample parts in relation to each other, in this case, exhibited this type of feature and showed in general, that the cracks propagated from the front of the canopy.

Epoxy bond

The epoxy bond was examined using differential scanning calorimetry to determine the extent of the resin cure. This showed that the epoxy bond was fully cured.

Other canopy failure

The AAIB became aware of another investigation involving an apparent failure of a canopy of an Extra NG in flight. This involved Extra NG registration SP-HMM on the 18 March 2022 that was investigated by the Polish authorities.

Their report stated that without warning the canopy had opened in flight, broken up and detached, leaving debris over the airfield. One of the two occupants suffered a minor cut to their face, which the report stated was probably caused by their headset as it was blown away. The aircraft landed safely and, apart from the loss of the canopy, the aircraft was otherwise undamaged.

The reported damage to the canopy transparency and frame appeared to be similar to that found on G-MIIL. In particular, the left side outer frame covering the centre shoot bolt mechanism had detached and revealed only a narrow bonding bead along the top edge. The right side rear section of frame attached to the rear hinge had broken in a similar manner to that of G-MIIL. Of note, the shoot bolts had been driven to the closed position by the spring similar to G-MIIL. The corresponding fuselage lugs were also completely intact.

The Polish investigation[6] concluded that the probable cause of the accident was vibration of the canopy frame caused by a loss of stiffness. This led to the shoot bolts unlocking and the canopy detaching from the aircraft. It identified three contributory factors:

- *A probable crack in the canopy frame in the flight before the occurrence (or earlier).*
- *Loosened rear fitting of the canopy locking system.*
- *Accelerating the aircraft to a high speed, close to VNE.*

Analysis

The aircraft was being flown straight and level on its return to base after having completed a series of aerobatic manoeuvres when the accident occurred. The loss of the canopy had left the pilot seriously injured and unable to see sufficiently to continue flying the aircraft. It was only as a result of him wearing a parachute that he had the option of bailing out of the aircraft before he would have otherwise likely lost control of the aircraft whilst onboard.

Footnote

6 PKBWL Serious Incident/2022/1097.

Had he been wearing a helmet with a suitable visor, it is probable he would have avoided being injured and would have been capable of continuing to fly the aircraft and land. The use of such helmets is, however, not widespread and the pilot had never anticipated he may lose the canopy in-flight. Whilst aircraft accidents remain relatively rare events, when they occur, the difference that may be afforded by wearing a parachute or helmet are clear.

The investigation considered a number of potential causes.

Foreign object impact

No evidence was found of an impact with a foreign object.

Had the aircraft struck a bird then the investigation would expect to find remains on either the aircraft structure, pilot or both. Similarly, had the aircraft struck a UAV then it would have been highly likely that parts from the UAV would be discovered during the detailed search of both wreckage sites.

The loss of a propeller blade or component from the engine striking the canopy was considered. However, data from the EFIS was inconsistent with either a failure of the engine or propeller throughout the flight and this was discounted.

Weather phenomena such as hail or ice accretion detaching and impacting the aircraft were also considered, but in this case the weather conditions on the day were benign.

Canopy release in flight

The manufacturer described how if a canopy were to open in flight, under aerodynamic forces it would rotate violently about its hinges to the right, breaking its restraint strap, with the unrestrained canopy hitting the right wing. This would result in the transparency fragmenting and the frame being damaged and probably detaching.

For the canopy to open, the shoot bolts and lugs would have to disengage. This could happen if an occupant was to operate the locking handle in flight. In this case the pilot is very clear that he correctly closed and locked the canopy whilst preparing for his flight. He flew with his left hand permanently on the throttle and had no reason to have touched the locking handle at any stage.

Despite the pilot's assertions that the canopy had been properly closed and locked, the case that he may inadvertently not have done so was also considered. The design of the shoot bolt mechanism and lugs can cause them to sit in a partially locked condition should the locking handle have not been pulled fully rearwards. In such a condition, the roller in the lug would not have travelled fully along the 'ramp' of its shoot bolt. As described by the manufacturer, the aerodynamic forces on the canopy structure under normal or negative g loads would pull the canopy upwards against its hinges and shoot bolts. With the shoot bolt in the partially locked condition, a significant force of at least 270 newtons, three times the normal force required to squeeze the handles to open the canopy, would be needed in order to drive the shoot bolts to the open position. This is considered highly unlikely.

Conversely, if at any stage the aircraft was subject to positive g-forces over 1 g the canopy frame would be forced downwards relative to the fuselage and would compress its weather seal. This would decrease the linear force acting on the shooting bolt ramp, allowing the shoot bolt spring to ease the shoot bolts rearward to the fully locked condition.

After takeoff, but prior to the aerobatics commencing, a maximum of 2.5 g and no negative g was recorded. During the aerobatics sequence a maximum of 3.6 g and minimum of -1.5 g was recorded.

Based on this information, it is considered implausible that the forces experienced by the locking mechanism would have been sufficient to act against the spring pressure keeping the shoot bolt in place had the canopy been only partially locked. Certainly, there were sufficient forces acting on the shoot bolt for it to remain closed during the outbound flight and aerobatic sequence and, in the absence of other interventions, should have remained so for the remainder of the flight.

Canopy structural failure in flight

The recovery of the majority of the canopy frame and transparency provided evidence of a rapid disintegration prior to the canopy hitting the ground. Examination of the recovered pieces of the frame showed an inconsistency of the bonding between the inner and outer frames of the canopy in numerous areas. These inconsistencies exhibited areas of porosity and adhesive failure between the bond and peel ply areas. On the left side of the canopy frame there was also evidence of only a very narrow bond bead as well as a small area within it where no bonding had taken place at all. The frame bonding did not appear to conform to the requirements set out on the cross-sectional schematics illustrated in the manufacturer's canopy assembly diagram.

The lack of uniformity in bonding around the canopy frame would have created a differential load transfer around the joint, leading to the development of localised stress points within the canopy acrylic. The test results concluded that this led to the initiation and propagation of fatigue cracks at the front of the canopy which, when the cracks reached a critical length, caused the catastrophic failure of the canopy. It is not known what the critical crack length was, or exactly where it initiated.

Subsequent break-up sequence

The evidence suggests that the frame assembly at the front of the canopy imparted differential loads into the transparency material in a small area causing fatigue leading to its break-up.

During part of that sequence the outer frame detached from the channel section surrounding the shoot bolt mechanism leading to a loss in its rigidity. As this happened, it is highly likely the continuing air flow loads on the pieces attached to that section wrenched the shoot bolts out of their roller lugs. In doing so, the remaining sections of the frame would have moved away from the lugs leaving the centre and rear reinforcing plates undamaged. The bends at the front and rear of the recovered shoot bolt illustrate the magnitude of the forces involved

(Figures 10 and 11). The absence of soil or organic matter on this part of the canopy and shoot bolts show this was not caused on impact with the ground. Had the shoot bolts also been caused to unlock from a partially locked condition, this extent of bend damage could not have occurred. This shows the damage was sustained as part of the canopy break-up sequence in flight. Figure 25 represents this sequence resulting in the canopy releasing itself from the shoot bolt lugs during its break-up.

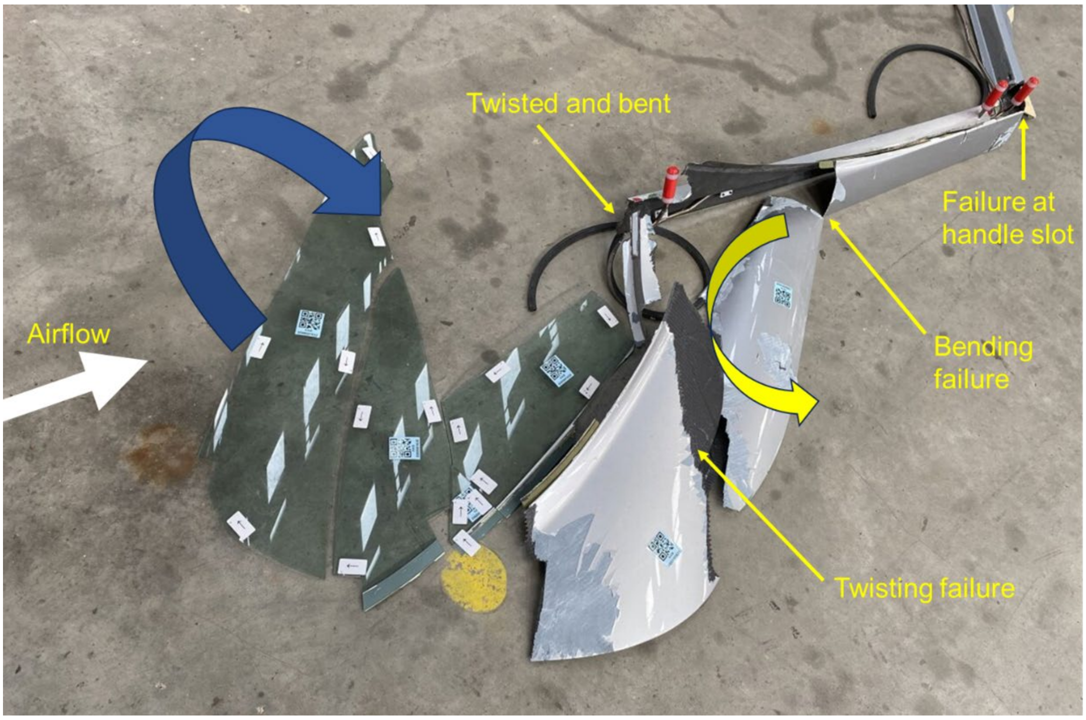

Figure 25

Canopy shoot bolt release and break-up sequence

Immediately the shoot bolts parted from the lugs the spring would have contracted, as it was designed to do, pulling the shoot bolts back into an apparently locked position.

It is considered that the canopy fitted to G-MIIL broke up without warning and whilst operating within the aircraft's certified flight envelope due to fatigue cracking of the acrylic transparency. The cracking was initiated by differential forces acting on the canopy frame, induced by inadequate bonding between the inner and outer frame. This, in turn, caused localised stresses being imparted into the transparency, presenting conditions which promoted fatigue crack development. This resulted in a catastrophic failure of the canopy when cracks reached a critical length. The following Safety Recommendation is therefore made.

Safety Recommendation 2024-004

It is recommended that the European Union Aviation Safety Agency (EASA) ensure the canopies fitted to all Extra NG aircraft are manufactured to meet the required certification standards and can withstand expected aerodynamic and flight loads.

Service Bulletin NG-2-22

This introduced a foam adhesive into the void at the front of the canopy frame.

The SB stated that this was to rework the adhesive glue between the inner and outer canopy frame. The adhesive ability of the foam is unknown in this situation due to the existing state of surfaces it contacts and the extent to which it penetrates the void due to existing epoxy bond bead lines and any exposed peel ply surfaces.

In addition, as the foam adhesive is only applied at the front of the canopy, the SB does not rectify the anomalies found in the quality of the inner and outer canopy frame bonding on both sides of the canopy or its hinge pin brackets.

In view of these potential issues, the following Recommendation is made.

Safety Recommendation 2024-005

It is recommended that the European Union Aviation Safety Agency (EASA) assess the effectiveness of SB-NG-2-22 in rectifying inadequate bonding.

Conclusion

It is considered the canopy of the aircraft suffered a catastrophic failure in flight due to fatigue cracking of the acrylic transparency. The cracking was initiated by differential forces acting on the canopy frame, induced by inadequate bonding between the inner and outer frame. This, in turn, caused localised stresses being imparted into the transparency, presenting conditions which promoted fatigue crack development. This resulted in a catastrophic failure of the canopy when cracks reached a critical length.

The pilot was not wearing a helmet or a visor and received serious facial injuries. He was unable to continue flying the aircraft in order to land and it was only due to the fact he was wearing a parachute that he was able to bail out and survive. It was only chance that the abandoned aircraft did not injure anyone when it hit the ground in a built-up area.

Safety action

Discussion with the manufacturer highlighted concerns regarding the canopy closing and locking instructions in the POH which did not make it clear that the locking handle must be manually pulled fully rearwards to ensure that the shoot bolts are in the fully locked condition.

The manufacturer introduced the following amendment to the POH:

'To lock the canopy:

Pull together the interior locking handles.

Close the canopy. Verify the canopy reaches the closed position.
Release locking handles.

Pull the aft locking handle fully rearward to the end stop. Verify handle is in the LOCK position (green marking).'

Appendix A

Comments of the Bundesstelle für Flugunfalluntersuchung (BFU) representing the State of Design and Manufacture

Chapter 6.3 of Annex 13 to the Convention on International Civil Aviation provides that the State conducting the investigation shall send a copy of the draft Final Report to all States that participated in the investigation, inviting their significant and substantiated comments on the report as soon as possible. If the State conducting the investigation receives comments within the period stated in the transmittal letter, it shall either amend the draft Final Report to include the substance of the comments received or, if desired by the State that provided comments, append the comments to the Final Report.

Bundesstelle fur
Flugunfalluntersuchung
German Federal Bureau of Aircraft Accident Investigation

BFU

Accident involving Extra NG, G-MIIL, at Upper Heyford, Bicester, Oxfordshire on 02/04/2022 - Comments to Draft Report

The BFU, representing the state of design and manufacture, does not agree with the analysis resulting in a scenario of a canopy failure in flight, due to fatigue cracking of the acrylic transparency. This scenario can be ruled out since it does not explain how the locking mechanism opened and released the remaining parts of the canopy frame. It is incomprehensible how the continuing air flow loads on the pieces of the broken canopy frame attached to that section wrenched the shoot bolts out of their roller lugs as it is described in the analysis. Any airflow during forward flight will create strong forces directed to the aft, which will force the locking mechanism into the locked position and not open it.

Taking all facts into account, especially the undamaged shoot bolts and lugs, it is most probable that the canopy was not completely locked prior to the flight and the locking mechanism opened completely at some point, due to air loads and vibration. Even if one would expect that such an event would more likely occur during aerobatic flight, it is anything but unlikely during level flight. Finally, the draft does not include any facts which contradict this scenario.

Considering the cockpit design and the experience of the pilot, the BFU agrees that it is quite unlikely that the pilot opened the canopy inadvertently.

Published: 22 February 2024.

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.

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.

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.

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.

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.

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).

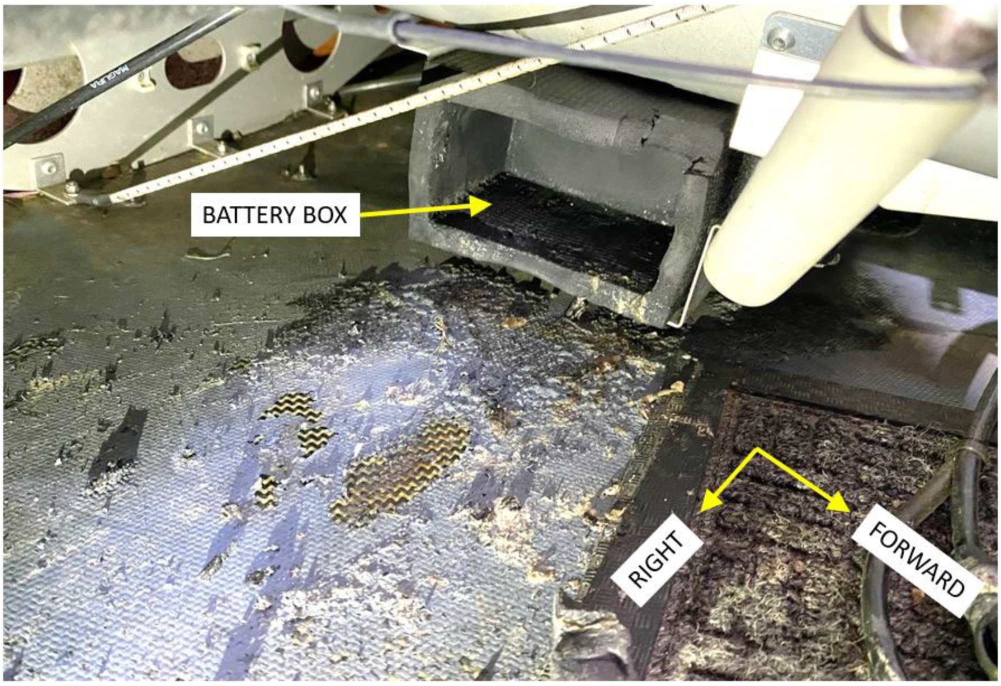

Figure 3
Damage to the cabin floor caused by the battery fire

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).

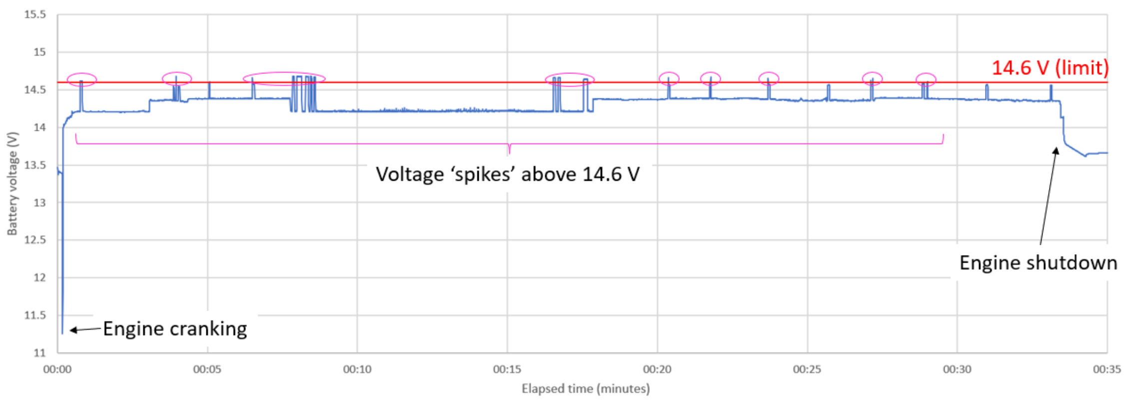

Figure 5
Battery voltage recorded during G-CICF test flight

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)

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.

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.

Published: 22 February 2024.

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:	AS355F1, G-BOSN
No & Type of Engines:	2 Allison 250-C20F turboshaft engines
Year of Manufacture:	1982 (Serial no: 5266)
Date & Time (UTC):	4 October 2023 at 1125 hrs
Location:	Gunnersbury Park, London
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew – 1 Passengers – 5
Injuries:	Crew – None Passengers – None
Nature of Damage:	Minor damage to right rear cabin door
Commander's Licence:	Commercial Pilot's Licence
Commander's Age:	32 years
Commander's Flying Experience:	2,164 hours (of which 84 were on type) Last 90 days – 105 hours Last 28 days – 29 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

Synopsis

During a commercial sightseeing flight, the helicopter's right cabin doors both opened unexpectedly. Unable to close the doors in flight, the pilot carried out an immediate landing on nearby parkland. Once on the ground he was able to establish the doors had sustained only minor damage and concluded they were likely not to have been securely locked before departure. He re-closed the doors, checked their locking pins were correctly located, and continued the flight as planned.

History of the flight

The helicopter was taking five passengers on a commercial sightseeing tour of London when, approximately 20 minutes into the flight, the cabin doors on the right side of the helicopter opened unexpectedly. The pilot could see the rear door had swung open and was "still attached but being held fully open by the airflow." The forward door was also ajar. Concerned by the risk of the rear door detaching, he elected to make an immediate landing at the nearby Gunnersbury Park.

After shutting the helicopter down the pilot saw there was minor skin damage on the rear door and that its window was cracked. The crack was contained, with no loose fragments, and appeared to have been caused by the window striking the baggage compartment hinge (Figure 1) when the door swung backwards as it opened.

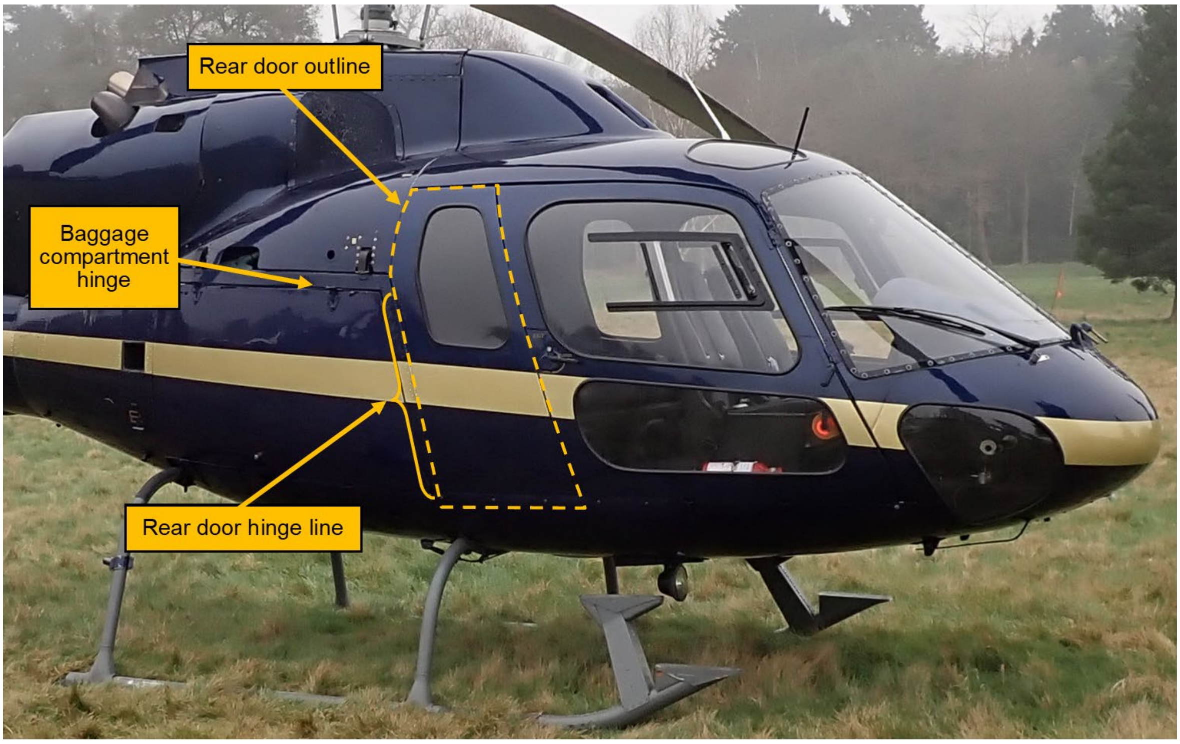

Figure 1
Doors on right side of G-BOSN (library image)

While on the ground at Gunnersbury Park, the pilot assessed the reason for the doors opening was they had likely not been securely locked before departure. He could not recall checking the rear door's locking pins were correctly located when he initially closed it. He also reported that because he "closed the front door from a seated position which is slightly awkward [he] might not have properly secured it to the rear door."

After checking the passengers were happy to continue, the pilot re-closed the doors, confirmed they were securely attached and locked, and completed the planned flight without further incident.

The pilot reflected that a more thorough check of all four doors' security prior to the initial departure would likely have prevented the incident.

Accident

Aircraft Type and Registration:	Cessna 120, G-BRUN	
No & Type of Engines:	1 Continental O-200-A piston engine	
Year of Manufacture:	1946 (Serial no: 9294)	
Date & Time (UTC):	15 September 2023 at 1420 hrs	
Location:	Kittyhawk Aerodrome, Sussex	
Type of Flight:	Private	
Persons on Board:	Crew – 1	Passengers –.1
Injuries:	Crew – None	Passengers – None
Nature of Damage:	Engine shock loaded, wing and nose fuselage damaged	
Commander's Licence:	National Private Pilot's Licence	
Commander's Age:	66 years	
Commander's Flying Experience:	400 hours (of which 3 were on type) Last 90 days – 3 hours Last 28 days – 3 hours	
Information Source:	Enquiries made by the AAIB	

Synopsis

As the aircraft touched down it bounced, and the pilot initiated a go-around. Reacting to a concern raised by the passenger, the pilot pushed the control yoke forward which resulted in the aircraft touching down firmly at the edge of the runway where it contacted vegetation and rolled over.

History of the flight

The pilot, arrived at the airfield where he kept his aircraft with the intention of flying, but because of his own assessment of the weather conditions he initially decided not to fly. However, following a conversation with an acquaintance, who was an experienced pilot and instructor familiar with the airfield, he decided to fly with his acquaintance who accompanied him as his passenger and not as a flying instructor. The takeoff and departure was normal, but the pilot reported that it was "quite a thermally sort of day and he was being thrown around a bit". Therefore, he decided to return to the airfield.

Unhappy with his approach to land at the airfield, he initiated a go-around. His passenger agreed with his decision. On his second approach, the passenger may have made a comment about the height which the pilot adjusted by aiming to land further down the runway. The aircraft touched down firmly and bounced, and the pilot initiated another go-around. While the aircraft nose rose quite steeply, the aircraft appeared to sink and drift rapidly off the centre line towards the edge of the runway. At this point the pilot believed the passenger suggested "push forward" on the control yoke. The pilot responded and the aircraft touched down firmly, bounced and then contacted vegetation at the edge of the runway causing it to cartwheel over a nearby fence. The aircraft came to rest upside down.

Pilot's analysis

The pilot considered there were several factors which led to the accident.

- He normally liked to take his time and prepare methodically for a flight. On this occasion, after having decided not to fly, his change of mind was spontaneous, and he did not prepare for the flight to his own satisfaction.
- He was unclear as to the role of the passenger, and perhaps overreacted to comments from him.
- He was still familiarising himself with G-BRUN which he had recently acquired and had only flown three hours, all under the supervision of another qualified instructor.
- All his hours as PIC had been in an aircraft with a stick rather than yoke control. He believed that the difference in feedback through the different type of controls caused him to over-control.

Passenger's comments

The passenger reported that he was not acting in an instructional role during this flight. However, this did not preclude him from making comments or suggestions solely from a flight safety perspective. He considered that he was unlikely to have used the phrase "push forward" and would have said, in this situation, "nose down". He was expecting the pilot to adjust the attitude to climb away or prevent a stall rather than what he considered to be a "coarse" input from the pilot.

The passenger also acknowledges that regardless of the suitability or not of the weather conditions, a decision to fly rests solely with the pilot in command and considers he would not have unduly influenced him to fly.

AAIB comment

The AAIB has previously reported on accidents and serious incidents where the role of an instructor flying as a passenger has not been clear. It is possible in this case that the pilot had a heightened sense of security because his passenger was an instructor and went ahead with the flight which he was not confident to undertake in the conditions.

Serious Incident

Aircraft Type and Registration:	Denney Kitfox MK2, G-BUKP	
No & Type of Engines:	1 Rotax 582 piston engine	
Year of Manufacture:	1992 (Serial no: PFA 172-12301)	
Date & Time (UTC):	3 September 2023 at 1300 hrs	
Location:	Near Old Buckenham Airfield, Norwich	
Type of Flight:	Private	
Persons on Board:	Crew – 1	Passengers – None
Injuries:	Crew – None	Passengers – N/A
Nature of Damage:	None	
Commander's Licence:	National Private Pilot's Licence	
Commander's Age:	55 years	
Commander's Flying Experience:	99 hours (of which 28 were on type) Last 90 days – 11 hours Last 28 days – 7 hours	
Information Source:	Aircraft Accident Report Form submitted by the pilot and further AAIB enquiries	

Synopsis

The aircraft was flown with an underslung cargo pod on a cross country flight which may have resulted in higher than anticipated fuel consumption. The pilot recognised a low fuel situation and planned a landing at Old Buckenham to refuel. Before arrival, the engine started to lose power, so the pilot initiated a field landing. There was no damage or injuries.

History of the flight

The pilot planned a cross country flight over two days from Grove Farm, west of Lowestoft, to Wharf farm, to the west of Leicester, and return. The pilot wished to carry some additional baggage, so he planned to conduct the flight with an underslung cargo pod fitted.

The planning was conducted using statute miles because the aircraft ASI was calibrated in mph. The planned route was 133 miles each way and the pilot planned to fly at a cruise speed of 65 mph. Based on this he calculated a minimum flight time of four hours 40 minutes including 30 minutes for a potential diversion and not allowing for wind. The pilot understood the normal fuel requirement for the aircraft to be 10 litres per hour (lph), giving a minimum fuel requirement of 47 l. The pilot allowed a 25% increase in fuel to account for the additional drag caused by the cargo pod, giving 59 l required for the trip without allowing for wind. The aircraft was fuelled with 65 l and there were 5 l in the header tank, so it departed Grove Farm with 70 l total fuel on board.

During the outbound flight the pilot found that an rpm increase (from 4,900 rpm to 5,150 rpm) was needed to maintain the planned airspeed. The pilot stated there was a slight tailwind and the flight time was, as expected, two hours and five minutes.

There were no fuelling facilities at Wharf Farm. The pilot checked the fuel level prior to the return flight using the sight tube and judged it to be sufficient for the return flight.

The return flight proceeded with a light southerly wind. Just over halfway, the pilot noticed that the wing tank sight tube was reading lower than anticipated and planned a stop for fuel at Old Buckenham. North of D208, approximately 10 nm from Old Buckenham, the low fuel indicator in the fuel header tank was triggered. The pilot yawed the aircraft to encourage fuel visible in the wing tank sight tube to flow into the header tank, but the warning remained illuminated.

The pilot decided to continue to Old Buckenham and advised them of the fuel situation but planned to initiate a field landing at the first indication of rough running. As he proceeded, he continuously assessed the available fields so that a preferred field was always in mind.

Just before joining the circuit for Old Buckenham, the pilot observed a reduction in rpm and immediately initiated a landing in the current preferred field. He informed Old Buckenham of his intention and, when prompted by Old Buckenham, declared a MAYDAY. The landing was completed without damage or injury and the MAYDAY was cancelled. The aircraft had been flying for approximately 1.5 hours since departing Wharf Farm. After landing, the pilot noted that approximately 5 l of fuel remained and this drained into the fuel header tank when the aircraft was in the tail down position.

No fuel leaks or other causes of unexpected fuel consumption were identified, and fuel consumption returned to normal when the cargo pod and additional weight were removed.

Aircraft information

The aircraft uses Avgas 100LL and is approved to fly using Mogas. It has two wing tanks of approximately 50 l and 20 l capacity with a constant gravity feed to a 5 l header tank mounted behind the seats. The header tank has a sensor that detects any airgap in the tank greater than 100 ml with an associated red LED warning light.

The owners manual for the aircraft gives a fuel consumption of 7.9 lph for cruise at 65 mph. It states: '*These figures can be used as a general guide, but each builder should conduct his own flight test program to determine the exact performance of his own aircraft.*' The aircraft owner stated the aircraft normally consumed around 10 lph at 65 mph.

The larger wing tank is fitted with a sight tube visible in flight. It is uncalibrated and the reading changes depending on aircraft attitude. The pilot reported that part of the sight tube is obscured in flight in this aircraft.

The underslung cargo pod is an optional modification supplied by the manufacturer (Figure 1). G-BUKP's cargo pod was supplied to the aircraft builder with the aircraft kit and had been passed on with the aircraft to subsequent owners.

The aircraft manufacturer does not provide information regarding the effects of the luggage pod on aircraft performance.

The LAA has not accepted the cargo pod as a factory standard option for use in the UK, although it can be approved by modification application. This is due to concerns about how the pod and luggage is secured and not fuel consumption. G-BUKP had not been approved to use this modification.

The aircraft was rebuilt by the owner in 2018 when LAA *Type Acceptance Data Sheet (TADS) issue 6* was in effect. Issue 6 does not list the baggage pod as a standard option but does not preclude it either. The owner of the aircraft did not consider that an approval process would be required given that the pod was a standard option offered by the manufacturer, the aircraft was fitted with factory welded mounting points for it, and the aircraft had flown with it before under prior ownership. Issue 7 of the TADS, published after the aircraft had been rebuilt and inspected, provides an additional preamble in the 'standard options' section:

> '*List of standard manufacture's options that can be installed without the need for a mod application (also applies to aircraft post-build)*'.

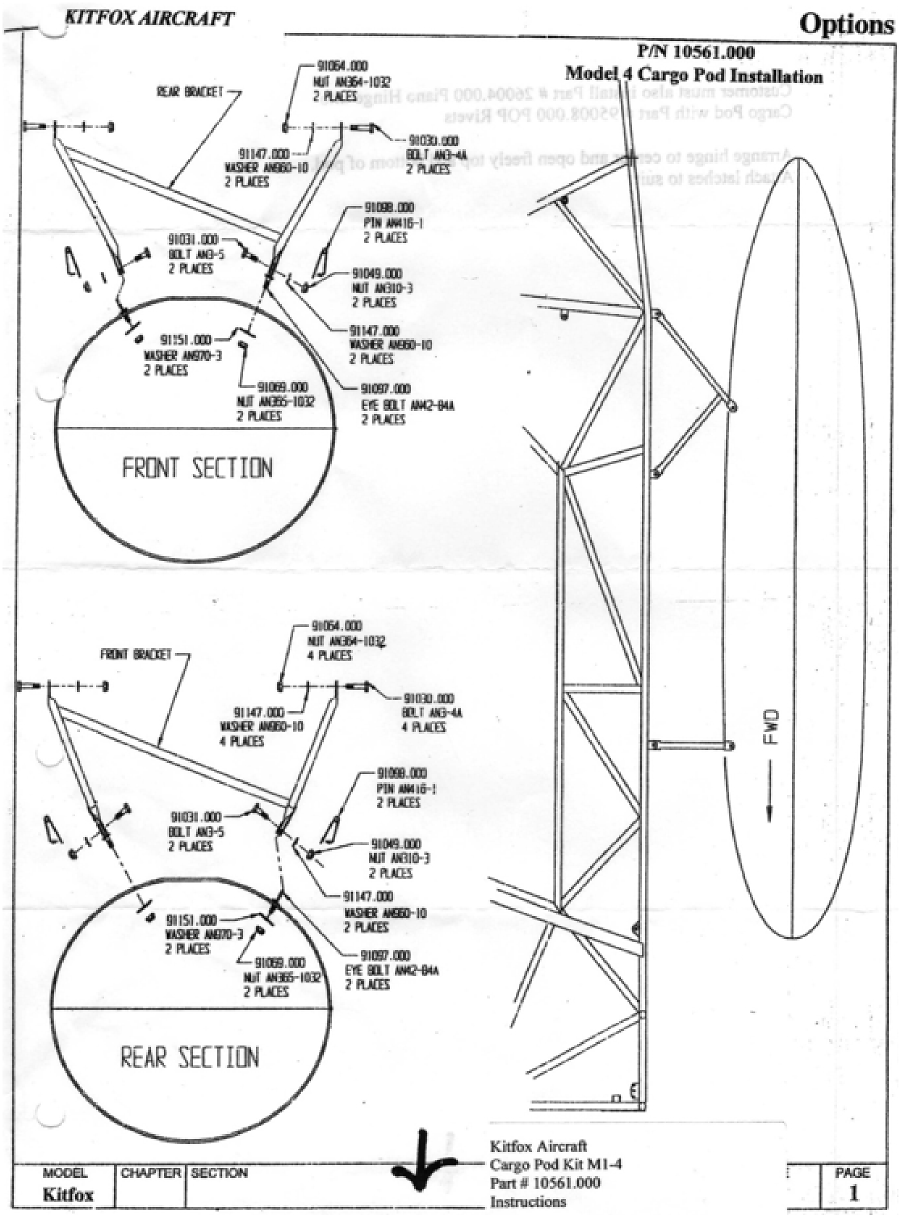

Figure 1

Illustration of the underslung cargo pod

Other information

Prior to the flight the pilot used social media to liaise with two other Kitfox owners who had used a similar cargo pod, and asked questions about the effect on performance. Both reported a small reduction in cruise speed and no significant difference in fuel consumption.

Before the incident flight, the pilot conducted two short flights with the pod fitted and noticed a speed reduction at the normal RPM setting but did not calculate fuel consumption.

There were NOTAMs in place for RAF Lakenheath, RAF Marham and Danger Area 208 which meant that these were not suitable alternate landing airfields and the pilot could not fly directly to Old Buckenham when he noticed that the remaining fuel was less than expected.

Relevant guidance

The CAA Skyway code[1] gives the following advice on fuel management:

> '*Fuel burn and range figures can be found in the AFM. You should have a good working knowledge of your aircraft's fuel burn at different power settings.*'

And

> '*Fuel gauges in most GA aircraft are not sufficiently reliable for the purposes of flight planning or pre-flight confirmation of fuel onboard. Physically examining the fuel levels with a method appropriate to the aircraft (such as a dipstick) is the best way of assessing the fuel onboard.*'

And

> '*Incorporate fuel burn into your PLOG calculations and/or flight plan on your VFR Moving Map device. Regularly check anticipated fuel burn against actual.*'

The Civil Aviation Authority of New Zealand's guidance document titled *'Fuel Management'*[2] contains additional guidance including an example fuel management log for use in flight. It states:

> '*It's good practice to check the fuel available before flight by at least two separate methods. We can do this by referring to the fuel gauge(s), loading a known quantity and, in many aircraft, by dipping the tanks.*'

> '*If the fuel tanks cannot be accurately or easily dipped, start the flight with the tanks either full, or filled to a fixed reference point, and keep an accurate inflight fuel log. If that's not possible, due to weight and balance or performance considerations, the only way to know exactly how much fuel is on board is to add a known quantity (ie, a reading taken from the fuel pump counter) to a predetermined reference point inside the tank.*'

Analysis

The cargo pod was not an approved factory standard option for use in the UK. To obtain approval, the aircraft owner was required to apply to the LAA for a modification but had not done so. Owners of LAA aircraft should note that only options listed in the 'standard options' section of the aircraft *Type Acceptance Data Sheet (TADS)* can be fitted without a modification application. The TADS that was current when the aircraft was rebuilt did not explicitly preclude use of the cargo pod or any other modification that was not in the 'standard options' list. This may have contributed to the misunderstanding. The next issue of the TADS was clearer but was published after the aircraft was rebuilt. The LAA has modified the TADS for this aircraft type to make it clearer that the underslung cargo pod has not been approved.

Footnote

1 Civil Aviation Authority (2023). *The Skyway Code, version 4*. CAA Skyway Code MK4 [accessed on 12/12/2023].

2 Civil Aviation Authority of New Zealand, *Fuel Management* https://caanz.cwp.govt.nz/assets/publications/gaps/caa-gap-fuel-management-web.pdf [accessed on 12/12/2023].

The pilot attempted to find out what effect the cargo pod would have on fuel consumption but there was no reliable information available from the manufacturer or other owners. The pilot allowed more than 25% extra fuel, but this was insufficient. If the aircraft was loaded with 70 l of fuel, allowing 10 minutes for taxiing, the engine ran for approximately 3 hours and 45 minutes and consumed 65 l of fuel, giving a consumption rate of around 17 l per hour with the cargo pod fitted. This is much higher than the normal fuel consumption figures given by the owner and the aircraft owners manual. The investigation did not verify the amount of fuel loaded, and it is not known to what extent the cargo pod or another factor may have influenced the fuel consumption.

The Civil Aviation Authorities of the UK and New Zealand both recommend accurately determining the amount of fuel available before flight with a calibrated gauge or dipstick, or by loading a known amount. They also recommend monitoring expected fuel burn against actual fuel burn in flight and keeping a record of this. In this aircraft, the uncalibrated sight tube was the only means to check fuel remaining prior to departure and in flight. Without being able to refuel, the pilot had no means to accurately check the amount of fuel on departure. There was also no accurate way to determine that the amount being consumed was much higher than expected. The aircraft owner plans to install a fuel flow sensor. This could be used in future to obtain more accurate fuel consumption figures for the aircraft with and without the cargo pod.

The pilot identified the low fuel situation early enough to make decisions about what to do in an unhurried manner but not early enough to land at a suitable airfield for fuel. The pilot's plan to land at the first sign of fuel starvation and the process of continual field selection produced a successful outcome. The aircraft's STOL capabilities and the pilot's experience of landing at short farm strips helped to increase the chance of a successful landing.

Conclusion

The aircraft was flown with a modification that had an unknown effect on fuel consumption and the pilot attempted to account for this during planning. If the aircraft contained 70 l of fuel on departure from Grove Farm, the fuel consumption was much greater than anticipated and this was not identified at a stage when it was possible to reach a suitable airfield. The pilots' decision to perform an immediate landing at the first sign of power loss rather than attempting to continue to the airfield produced a successful outcome.

Accident

Aircraft Type and Registration:	Flylight Nine, G-CMRF	
No & Type of Engines:	1 Polini 303 piston engine	
Year of Manufacture:	2023 (Serial no: DA275)	
Date & Time (UTC):	17 November 2023 at 1405 hrs	
Location:	Darley Moor Airfield, Derbyshire	
Type of Flight:	Private	
Persons on Board:	Crew – 1	Passengers – None
Injuries:	Crew – None	Passengers – N/A
Nature of Damage:	Significant damage to right wing and propeller.	
Commander's Licence:	National Private Pilot's Licence	
Commander's Age:	70 years	
Commander's Flying Experience:	545 hours (of which 457 were on type) Last 90 days – 44 hours Last 28 days – 13 hours	
Information Source:	Aircraft Accident Report Form submitted by the pilot and further enquiries by AAIB.	

Synopsis

During flight, the rear base bar control wires disconnected from the wing keel tube when the securing bolt dropped out of the keel tube. The pilot managed to land the aircraft, but the right wing and propeller were severely damaged. The manufacturer has issued replacement bolts, castellated nut and cotter pin, updated the design drawings and added a pre-flight check of the keel fitting to the Pilot's Operating Manual.

History of the flight

Approximately five minutes after takeoff, the rear base bar control wires became detached when the attachment bolt fell out of its fitting at the rear of the keel tube. The pilot quickly realised what had happened and applied back pressure on the base bar to create tension on the front base bar wires to keep the aircraft aerodynamically balanced. Without the rear attachment lines, the pilot could only apply limited control of the pitch of the wing using the control wires attached to the nose. The engine was not shut down at this point for fear of unbalancing the aircraft. The pilot carefully turned the aircraft back towards the airfield, which was only a mile away, as he considered this the best option for landing safely. The weather conditions at the time were calm, which assisted him to keep the aircraft stable with minimal movement of the base bar during the approach. The aircraft touched down on the soft, boggy runway. The aircraft landed flat but it was nose heavy, therefore, once lift was lost on landing, the base bar control wires went slack and the wing fell forwards. Loss of the rear attachment wires meant the base bar was free to pivot on its keel tube fitting which allowed the right wing to fold around the rigid main post and foul the propeller. The aircraft came to a stop, the engine was shut down and the pilot egressed with no injuries. The right wing and propeller were badly damaged.

Aircraft information

The Flylight Nine is a Single Seat Deregulated (SSDR) aircraft[1] and was one of only two newly designed flexwing microlights under trial. The manufacturer stated that they follow BCAR Section S requirements as closely as possible when designing their machines despite their SSDR status.

Aircraft examination

Figure 1

Image from an onboard camera showing base bar cables attached.

Examination of the keel tube after the landing found that the bolt and nyloc nut[2] securing the rear control wires to the keel tube were missing. As the aircraft was a new product, cameras had been fitted to record the flight. Video footage showed the moment where the rear control wires slackened indicating that they had detached from the keel tube.

Footnote

1 '*In the UK, unlike two-seat Microlights, single-seat Microlights do not require a Permit to Fly, and as such are unregulated with regard to the airworthiness of the aircraft.*' British Microlight Association Technical Information Leaflet number 045, issue 4, '*Single-seat Microlights*', dated January 2018.

2 Also referred to as a nylon-insert lock nut. It is a nut with a nylon collar insert designed to elastically deform over the threads of a bolt as it is tightened, thereby resisting unwinding from the bolt during use.

Pictures of the aircraft that were taken soon after construction was completed showed that the bolt, which was fitted to the underside of the keel tube, was secured by the nyloc nut on top of the tube but there was only one thread visible protruding from the nut[3]. The nut and bolt must have been present during the pilot's pre-flight inspection because the rear cables would not have been connected and it would have been immediately noticeable that the wires were slack. Moreover, the pilot would not have been able to use the base bar to adjust the angle of the wing during taxi, takeoff and flight. Figure 1 shows the rear cables still connected between the base bar and the keel during the accident flight. It was likely that the nut vibrated loose and, as a result, the bolt fell out due to vibration and gravity.

The manufacturer has replaced the bolt with a longer variant and the nyloc nut with a castellated nut and cotter pin, (Figure 2). They updated the design documents for the aircraft to reflect this change and added the requirement for pilots to specifically check this fitting during their walk-round check in the Pilot's Operating Manual.

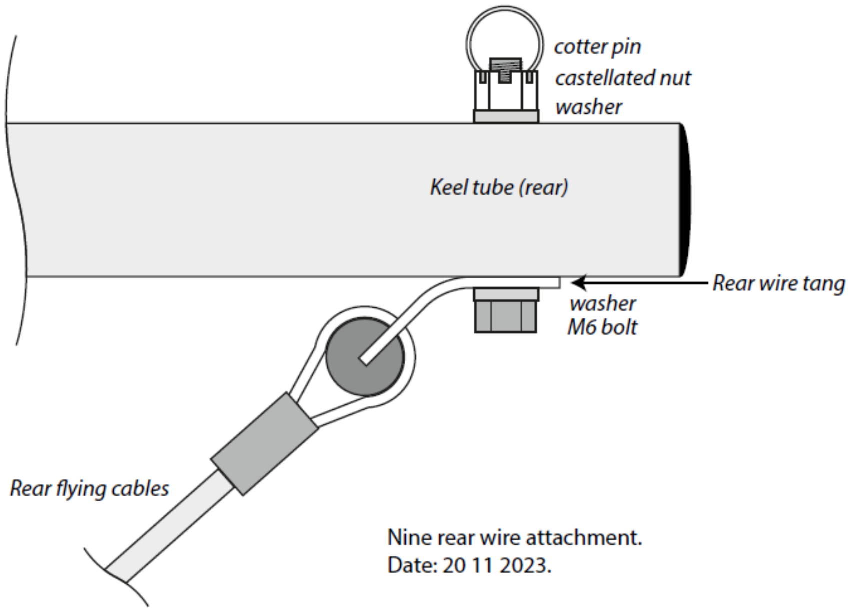

Figure 2

Diagram showing replacement castellated nut and cotter pin.

Conclusion

Failure of the nyloc nut and bolt that secure the base bar's rear control wires to the wing keel tube caused the wires to detach during flight. Despite the potential for aerodynamic instability, the pilot landed the aircraft successfully but the wing and propeller were badly damaged in the process. The manufacturer has issued longer replacement bolts and replaced the nyloc nut with a castellated nut and cotter pin and added the requirement for pilots to specifically check this fitting during their walk-round check in the Pilot's Operating Manual to prevent a recurrence.

Footnote

3 An engineering industry rule of thumb is that there should be two threads protruding though the nut to ensure all threads in the nut are engaged.

Accident

Aircraft Type and Registration:	RAF 2000 GTX-SE, G-CDJN
No & Type of Engines:	1 Subaru EJ22 piston engine
Year of Manufacture:	2005 (Serial no: PFA G/13-1363)
Date & Time (UTC):	15 September 2023 at 1405 hrs
Location:	Great Heck Airstrip, North Yorkshire
Type of Flight:	Private
Persons on Board:	Crew – 1 Passengers – None
Injuries:	Crew – None Passengers – N/A
Nature of Damage:	Rotor blades detached and aircraft damaged through water immersion
Commander's Licence:	Private Pilot's Licence
Commander's Age:	76 years
Commander's Flying Experience:	2,206 hours (of which 712 were on type) Last 90 days – 21 hours Last 28 days – 14 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

Synopsis

Shortly after takeoff, the gyrocopter lost performance and, from a low height, started to descend. The pilot manoeuvred away from a line of trees and conducted a forced landing in a nearby canal. The pilot considers that distraction had led him to leave the rotor brake applied and was the cause of the reduction in performance.

History of the flight

The pilot positioned his gyrocopter to take off towards the south from Great Heck Airstrip. The pilot was experienced on type, so he got in, started the engine and completed the checklists from memory. Whilst pre-rotating the rotor, he realised he had forgotten his pen and sun cap. He shut down the engine, applied the rotor brake, and exited the gyrocopter to get them.

When he re-entered the gyrocopter, he restarted the engine and later remarked that it took "an unusually long time" to pre-rotate the rotor to takeoff rpm, but he did not think about it further at the time. He took off and the gyrocopter initially climbed away, before starting to descend as it flew towards a canal which ran perpendicular to the end of the runway.

The pilot reported being startled by the descent and, as he could not fly over a line of trees ahead of him and there was a railway line to his left, he turned right to fly into wind along the canal. The canal banks were too narrow to land on without striking foliage, so the pilot decided to ditch in the canal. The main rotor struck the canal bank and detached during the ditching. The aircraft sank but the pilot escaped via the passenger door as the pilot's door was wedged against the canal bank.

Pilot's comments

Shortly after the accident, the pilot spoke with a friend who was in a nearby field, who told the pilot he heard a sound as if the engine speed was reducing. The pilot thought this was possibly the Doppler effect of the aircraft flying away from the friend's position as, although he did not have time to check his instruments, he thought the engine was working normally.

With hindsight, the pilot believes he left the rotor brake applied when he re-entered the aircraft after getting his pen and sun cap. He said that had he re-started his checklist from the beginning, he would have remembered to check that the rotor brake was disengaged before pre-rotating the rotor. G-CDJN was not fitted with a rotor brake warning light that would have served as a reminder; the warning light is not part of the standard RAF-2000 build kit. The pilot stated that, although the rotor brake is not particularly effective when cold, it would have become more so as it warmed up due to friction.

The pilot provided the checklists from another aircraft of the same type. There were two versions dated to 2001 and 2004, which both stated that the rotor brake can be engaged during taxi if one is fitted. Neither checklist had an item to check that the rotor brake is disengaged before engaging the main rotor clutch before takeoff. However, in the pilot's copy, a check '*rotor brake off, swing rotor*' had been added in pen at the start of the *'before starting engine'* checks.

The pilot owns another gyrocopter which has a rotor brake warning light installed. He remarked that he planned to install one on G-CDJN but had not got around to doing so.

AAIB comment

Performing checklists without interruption is important on all aircraft types. In this case, the interruption caused by needing to exit the aircraft probably resulted in the rotor brake being left applied. As the rotor brake warmed up due to friction, it would have become more effective, and this led to the loss of performance and resulting forced landing. Given that there was a railway line to his left and a tree line ahead, the pilot had limited options available to him and it was fortunate that he was able to exit the aircraft uninjured after it sank in the canal.

The checklist provided by the original manufacturer who supplied G-CDJN did not include a step to check that the rotor brake was disengaged before pre-rotation, but the pilot's copy had been amended by hand. The AAIB is unaware of any previous events in which the rotor brake had been left applied prior to takeoff and the manufacturer which supplied G-CDJN is no longer in business, so a Safety Recommendation to include this on the checklist is not deemed necessary. However, the AAIB has shared this finding with the organisation currently responsible for the RAF-2000 design.

Identifying available options before flight can improve forced landing outcomes if problems occur shortly after takeoff. This is particularly true where obstacles (such as buildings or railway lines), uneven terrain, woodland, or water are nearby which are not conducive to a safe forced landing. The CAA have published Safety Sense leaflets[1] which contain helpful information on strip flying and distraction.

Footnote

[1] https://www.caa.co.uk/general-aviation/safety-topics/safety-sense-leaflets/ [accessed January 2024].

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 investigations reviewed: January - February 2024

21 Sept 2023 **Piper PA-28-161** **G-BLVL** Netherthorpe Airfield, South Yorkshire

After setting takeoff power the airspeed indicator did not 'come alive' as the aircraft accelerated. The pilot aborted the takeoff with insufficient runway to stop the aircraft, which hit a hedge. The aircraft sustained some damage to the cabin.

6 Nov 2023 **Piper PA-28-161** **G-BODB** Sherburn In Elmet Airfield, North Yorkshire

On return from circuit flying the pilot intended to refuel his aircraft. Heavy rain precluded access to the refuelling station on the grass from the west and there were two aircraft parked on the east side of the pumps. Electing to taxi rather than to shut down and call for assistance from the ground handling team, the pilot misjudged the space available to taxi between the two aircraft and inadvertently struck one of them. He then attempted to pass between another parked aircraft and the pumps and inadvertently struck this other aircraft.

9 Jan 2024 **Reims Cessna F152** **G-PPLS** Dunkeswell Airfield, Devon

This was the first solo for a student pilot. The aircraft bounced on touchdown after which it stalled and dropped onto the runway. It ran onto the grass, then back onto the hard surface before coming to a halt. The propeller and nose gear were damaged. The pilot considered that a misjudged flare with the throttle at idle led to a reduction in airspeed and the stall.

9 Jan 2024 **SD-1 Minisport** **G-SJMW** Near RAF Lossiemouth, Moray

During cruise the engine lost power and started to run rough. The subsequent forced landing on a frozen field was slightly downwind and the pilot needed to avoid some power cables. With insufficient distance to stop the pilot attempted a ground loop, but this was ineffective due to the ground conditions. The aircraft collided with the boundary hedge, and the pilot escaped uninjured despite damage to his helmet.

16 Jan 2024 **Cessna 152** **G-TALC** Leicester Airport

A solo student was carrying out night circuits. On the third landing the aircraft encountered a crosswind which resulted in a bounce on landing leading to a propeller strike and collapse of the nose landing gear.

17 Jan 2024 **Piper PA-28-161** **G-LFSW** Perranporth Airfield, Cornwall

The student pilot flew the aircraft on a practice glide approach but touched down in the grass undershoot of Runway 04. When the aircraft then travelled onto the paved runway surface, the left main landing gear collapsed causing a slew to the left before coming to rest.

Record-only investigations reviewed: January - February 2024 cont

18 Jan 2024	**Jabiru J430**	**G-ROOO**	Near Earls Colne Airfield, Essex

The aircraft suffered a rough running engine in flight which, despite the use of carburettor heat, continued to run roughly. The pilot carried out a forced landing in a field and during the landing run the aircraft hit a rut which caused the nose gear to collapse

27 Jan 2024	**Titan T-51 Mustang**	**G-FION**	Netherthorpe Airfield, South Yorkshire

After takeoff, the aircraft made a climbing turn on to crosswind when the engine failed at approximately 450 ft agl. Its airspeed decayed, and it entered an incipient spin. The pilot was able to recover the aircraft to a normal attitude and make a forced landing in an uncropped field. The two occupants were not injured, but the aircraft was substantially damaged. The pilot later examined the automotive derived engine and found that a connecting rod had failed. He stated that aerobatic training, which included spin recognition and recovery, helped ensure a safe outcome.

28 Jan 2024	**Pegasus Quik**	**G-TBJP**	Sywell Aerodrome, Northampton

Just before rotation on the takeoff roll the aircraft slewed to the left then started to roll right. The instructor needed both hands to try and correct the roll and was unable to close the throttle and abort the takeoff. It is likely the student made inputs on the controls which increased the difficulty for the instructor to recover the attitude, and the aircraft toppled onto its side. Although the student did not recall touching the brakes, marks on the runway indicated they may have been inadvertently applied during the takeoff roll.

1 Feb 2024	**Ikarus C42 FB80**	**G-SHCK**	Bicester Aerodrome , Oxfordshire

The approach to Runway 34 at Bicester was stable, but the aircraft touched down heavily on the grass runway. It bounced then stopped quickly after the subsequent touchdown. The nose gear was damaged.

1 Feb 2024	**Reims Cessna F172P**	**G-BIOB**	Near Cobham, Surrey

During flight, the front left window was opened to take a photograph. However, the window hinge failed, and the window was then torn off by the airflow. The fully controllable aircraft was recovered safely to a nearby airfield and the window assembly, minus the hinge pin, was later recovered from a field.

Record-only investigations reviewed: January - February 2024 cont

12 Feb 2024 **Cessna 150D** **G-ASMW** Fife Airport, Glenrothes

Following an uneventful landing during circuit practice with an instructor, the student pilot turned the aircraft to taxi back to the threshold to take off again, when a strong gust of wind dragged the tail, resulting in the aircraft tilting onto its nose and causing damage to the fuselage.

16 Feb 2024 **Jodel D150** **G-BHVF** Henstridge Airfield, Somerset

The pilot reported that the weather was calm, and the approach was uneventful. The tailwheel aircraft developed a "wobble" during the landing run. The left wheel contacted the soft, wet, grass at the side of the runway causing the aircraft to slew to the left and ground loop, during which the right gear leg collapsed.

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).

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

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.

1/2021 Airbus A321-211, G-POWN
London Gatwick Airport
on 26 February 2020.

Published May 2021.

1/2023 Leonardo AW169, G-VSKP
King Power Stadium, Leicester
on 27 October 2018.

Published September 2023.

2/2023 Sikorsky S-92A, G-MCGY
Derriford Hospital, Plymouth, Devon
on 4 March 2022.

Published November 2023.

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
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)
FDR	Flight Data Recorder
FIR	Flight Information Region
FL	Flight Level
ft	feet
ft/min	feet per minute
g	acceleration due to Earth's gravity
GNSS	Global Navigation Satellite System
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

AAIB
Air Accidents Investigation Branch