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.

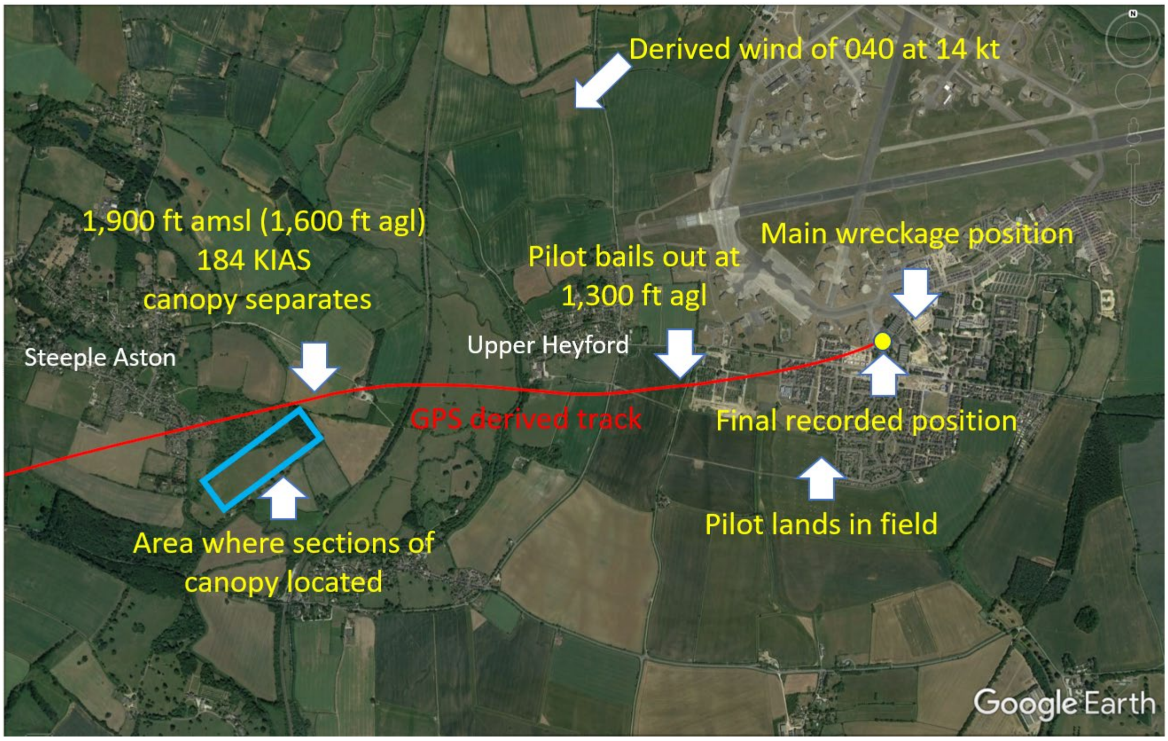

Figure 3

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.

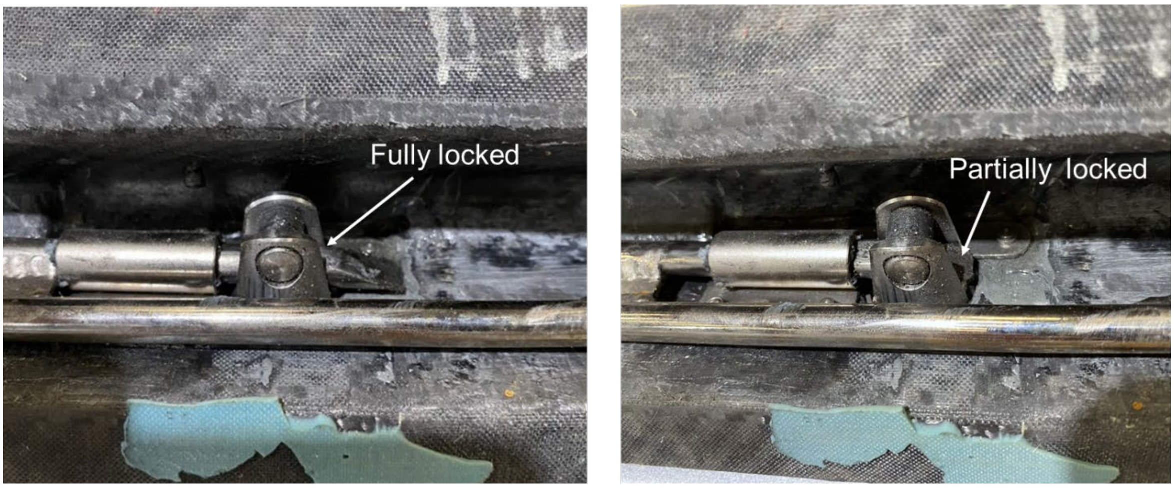

Figure 7

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

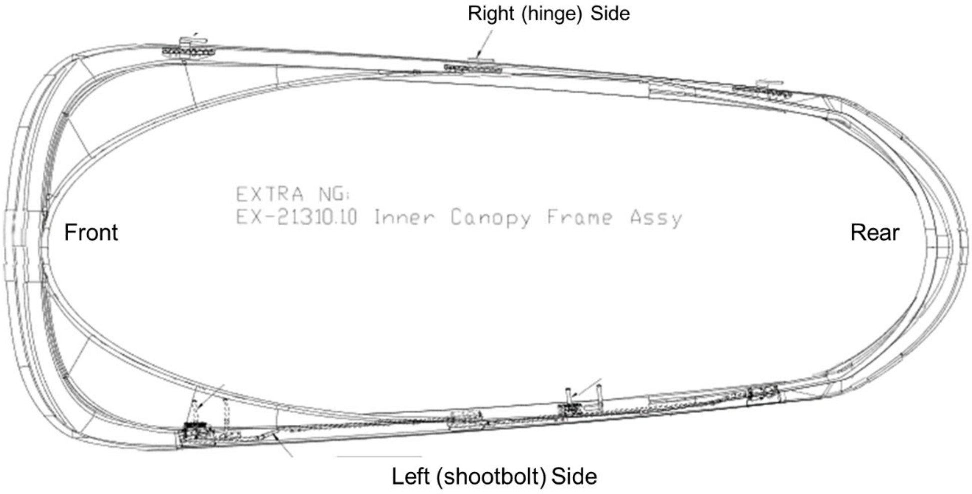

Figure 8

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).

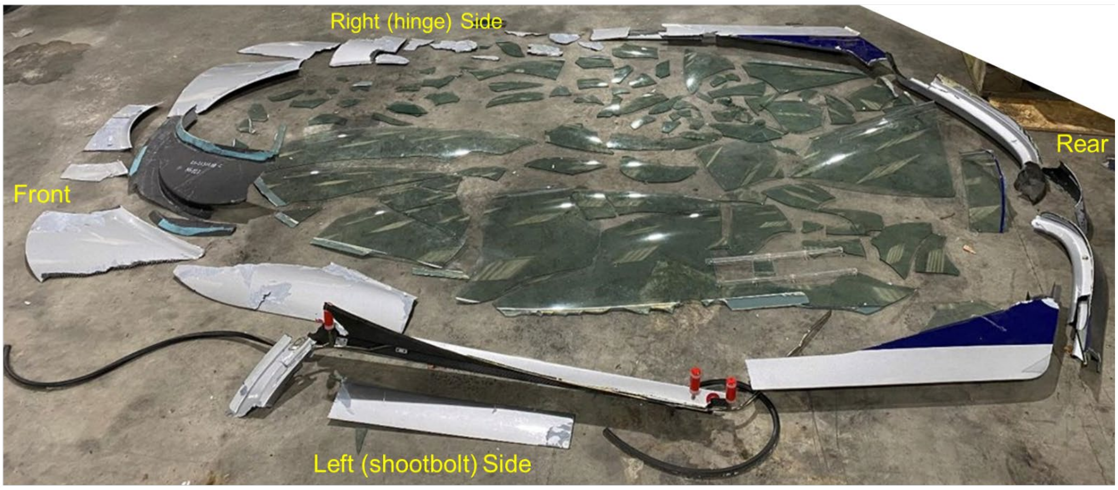

Figure 9

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.

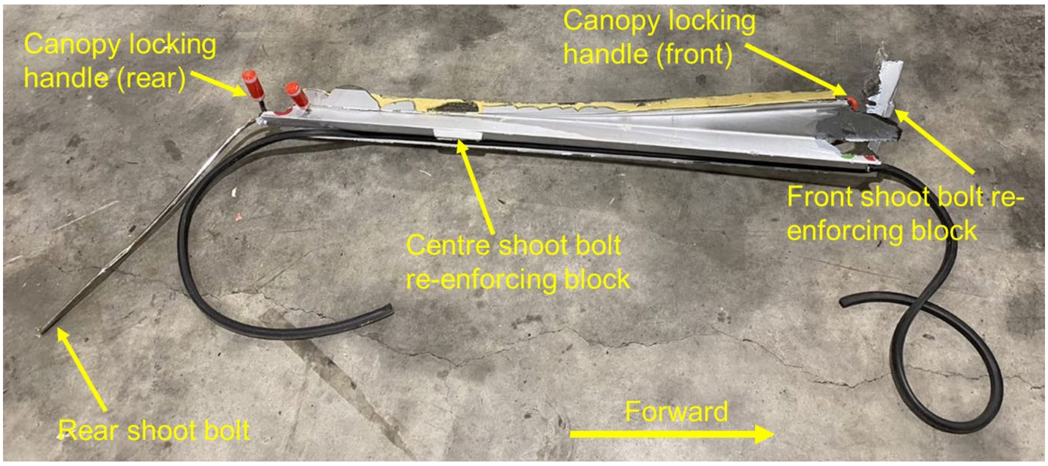

Figure 10

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).

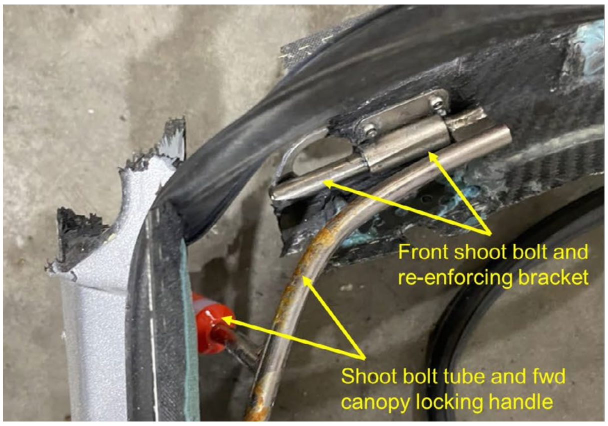

Figure 11

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).

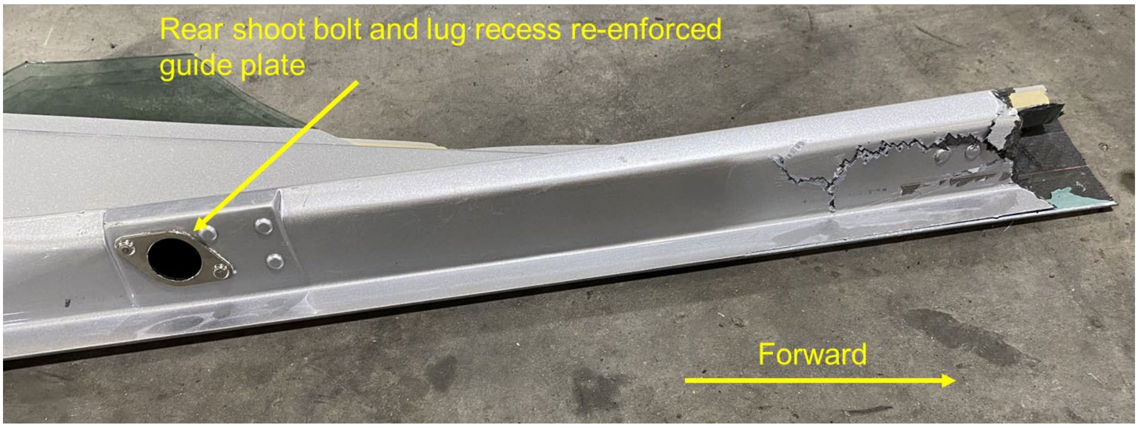

Figure 12
Left side rear canopy frame section

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.

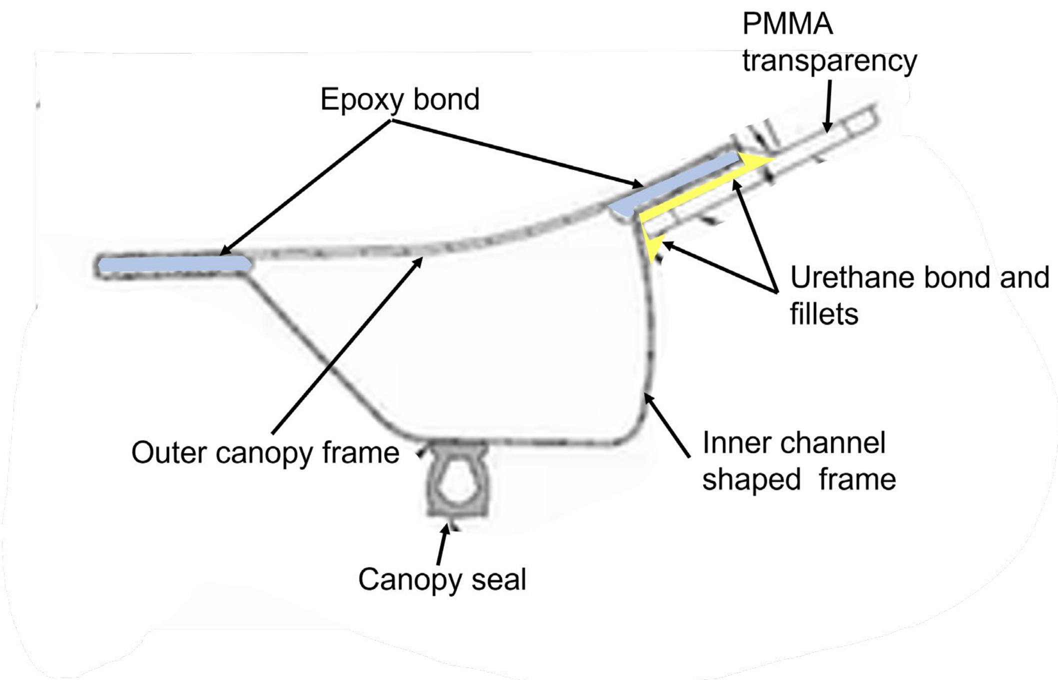

Figure 13
Schematic cross section of the front of the canopy frame assembly

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.

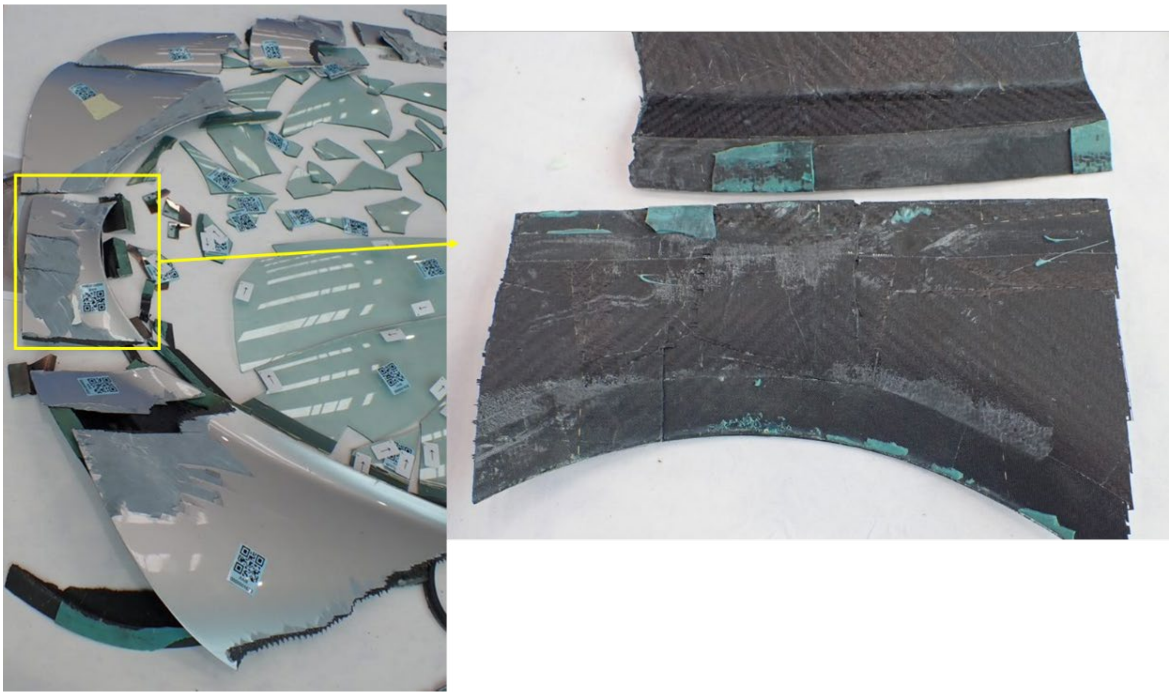

Figure 14
Canopy front section

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).

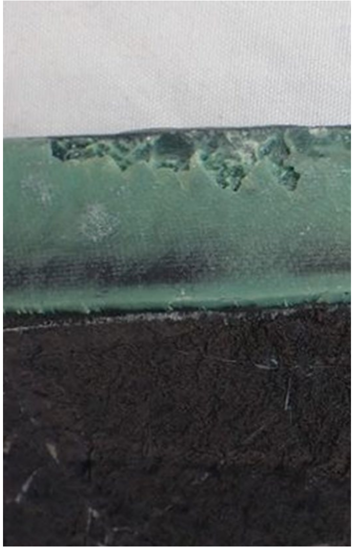

Figure 15
Epoxy bond 'crystalline' feature

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).

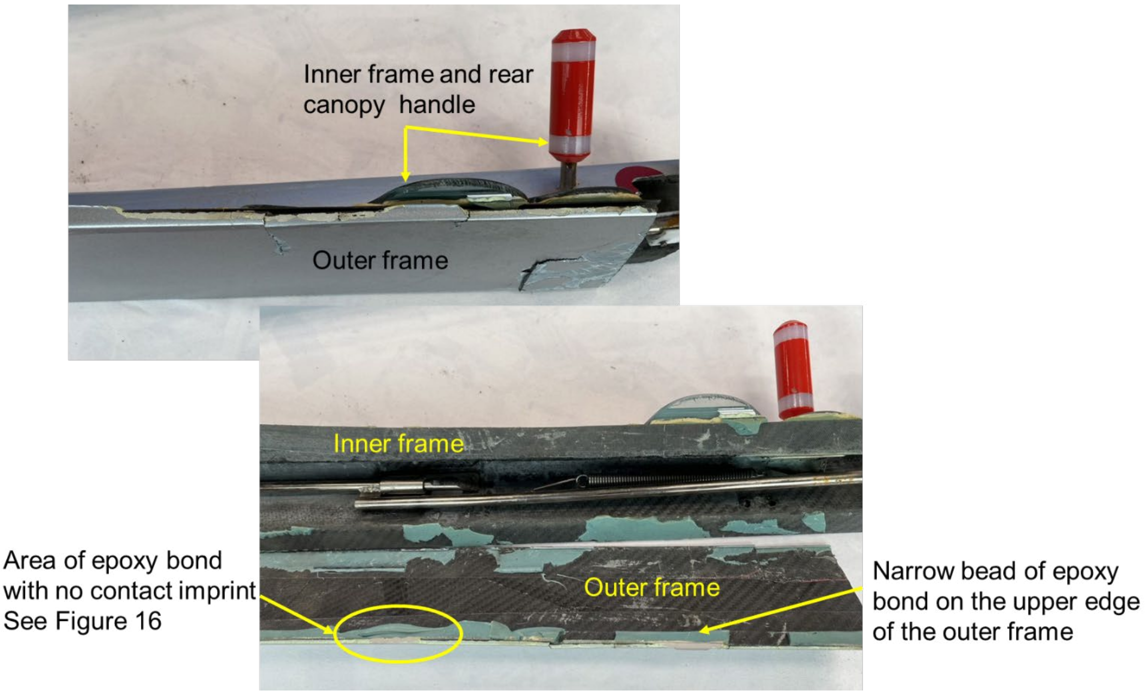

Figure 17
Canopy inner and outer frames left side

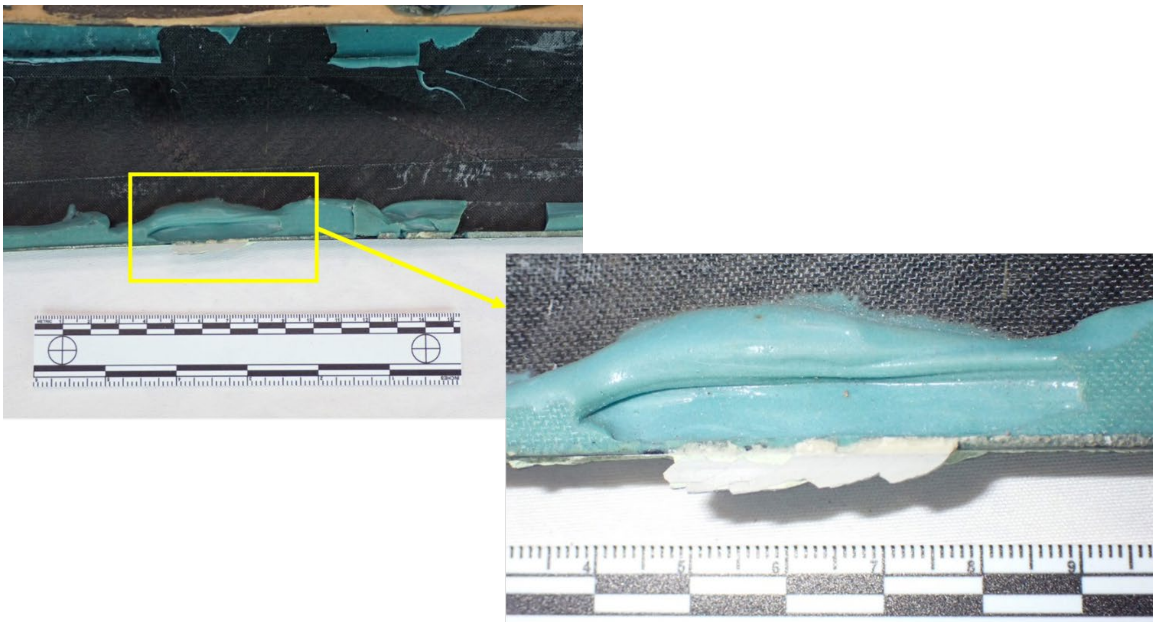

Figure 18
Area of epoxy bond showing there was no contact with the inner frame

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.

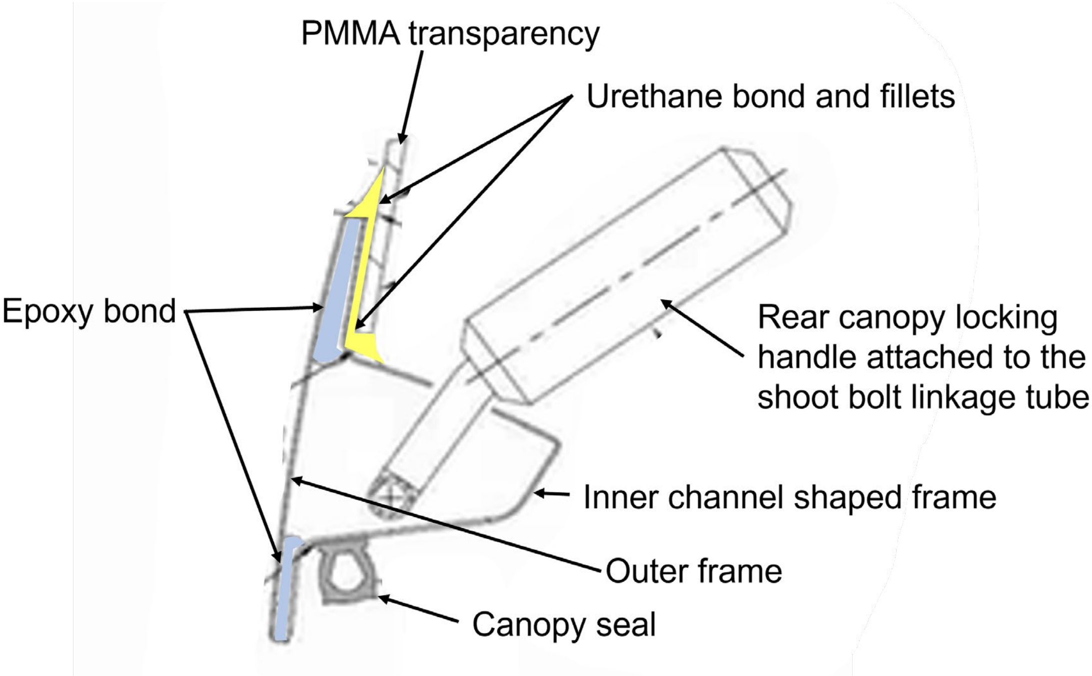

Figure 19

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

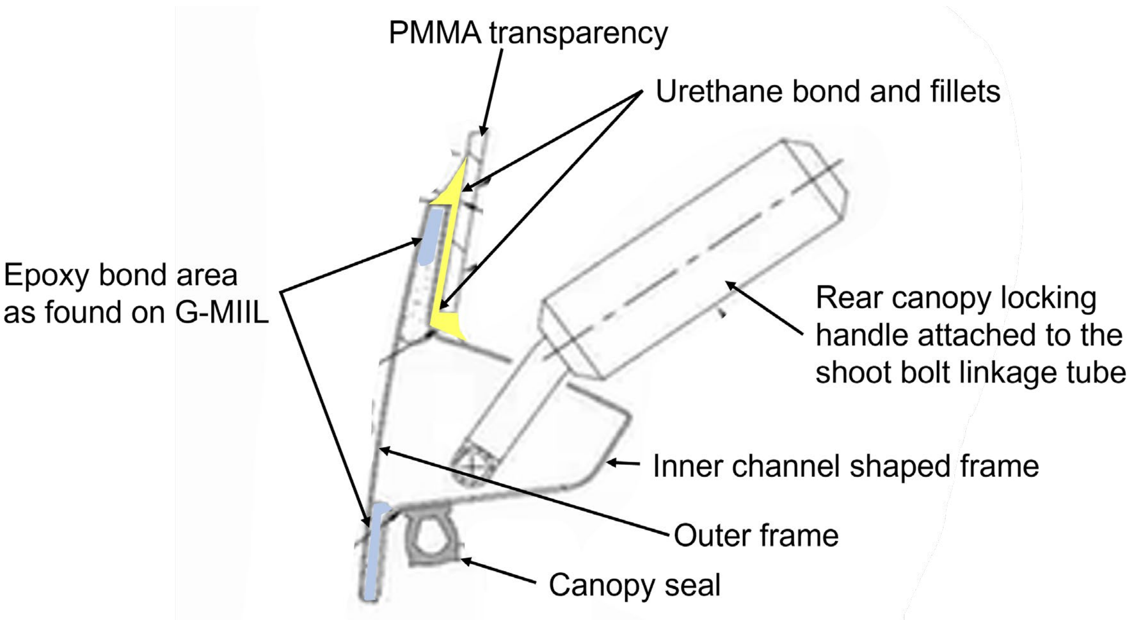

Figure 20

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).

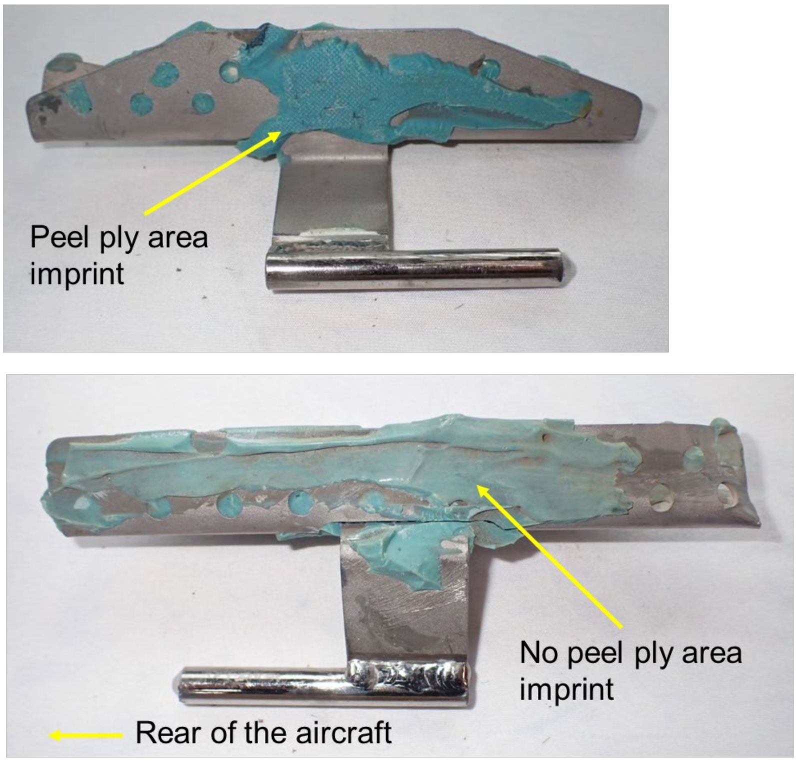

Figure 21

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.

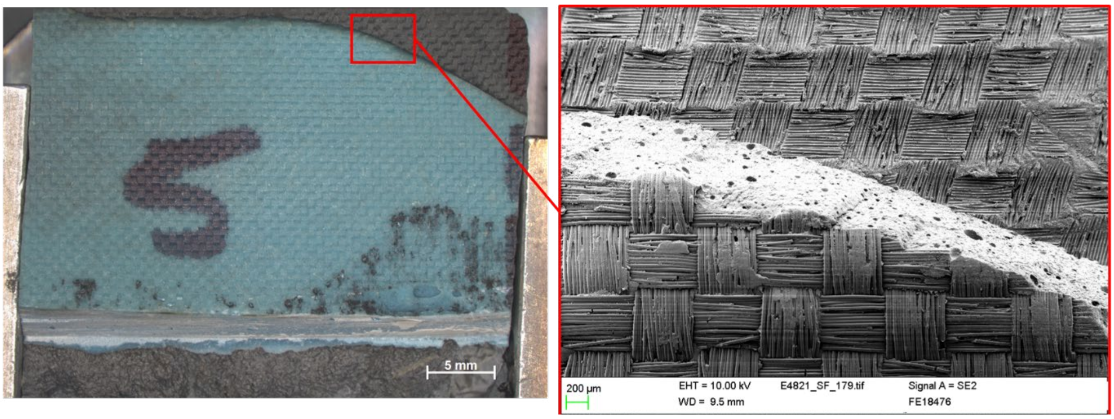

Figure 22

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.

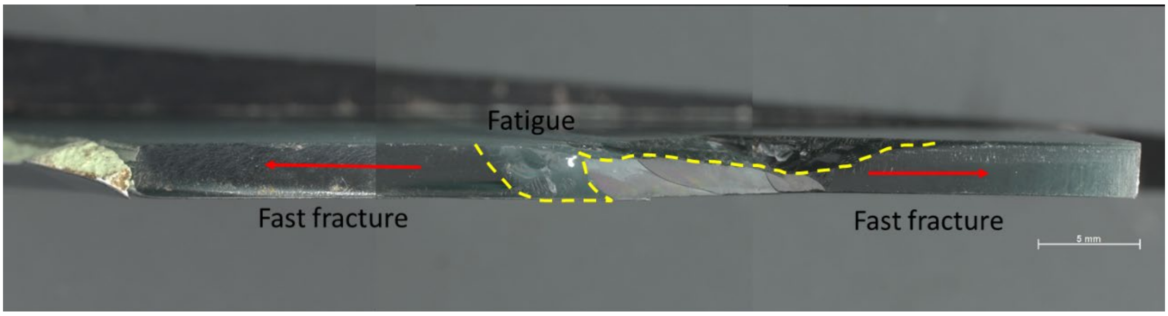

Figure 23
Evidence of fatigue and crack initiation

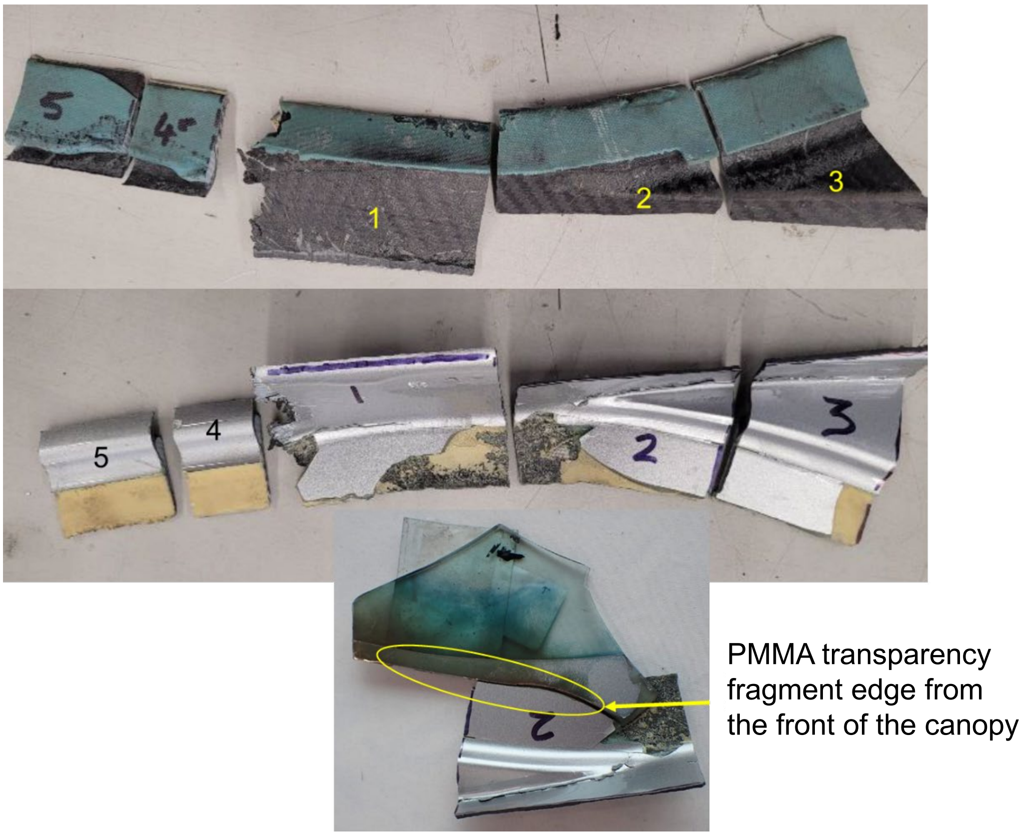

Figure 24
Parts of the inner frame from the front of the canopy (see also Figures 13, 14 and 15)

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.

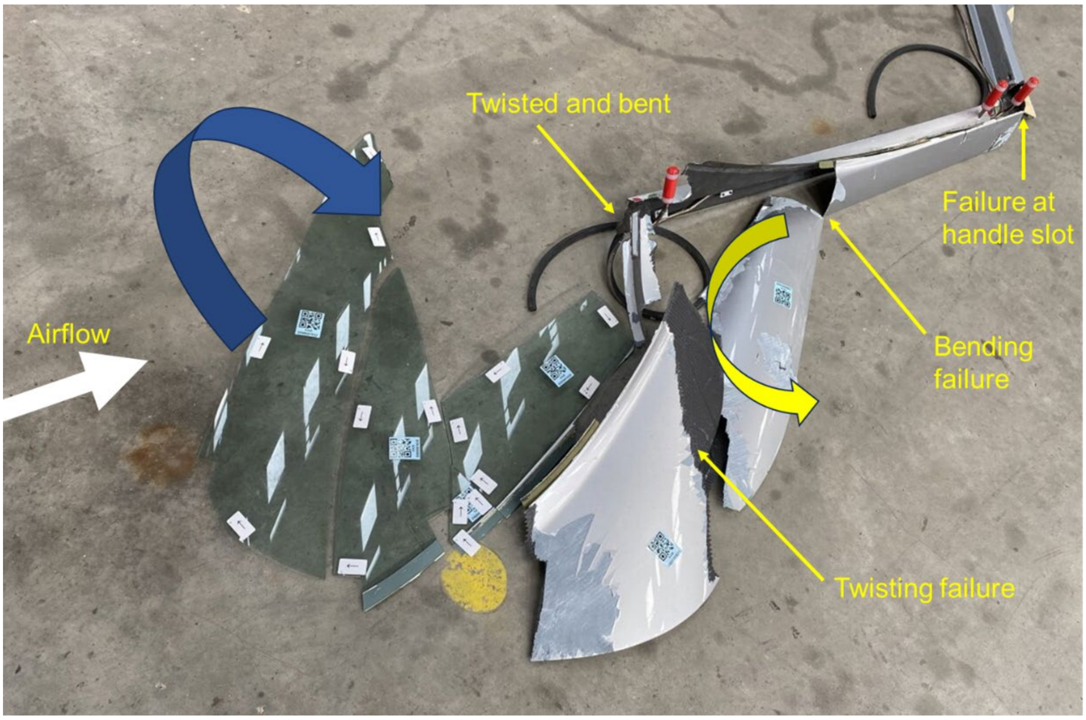

Figure 25

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.