ACCIDENT

Aircraft Type and Registration:	Folland Gnat T Mk 1, G-TIMM
No & Type of Engines:	1 Rolls-Royce Orpheus 101 turbojet engine
Year of Manufacture:	1962 (Serial no: FL519)
Date & Time (UTC):	1 August 2015 at 1302 hrs
Location:	Approx 1 mile north of Oulton Park, Cheshire
Type of Flight:	Aerial Work
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - 1 (Fatal) Passengers - N/A
Nature of Damage:	Aircraft destroyed
Commander's Licence:	Private Pilot's Licence
Commander's Age:	39 years
Commander's Flying Experience:	706 hours (of which 218 hours were on type) Last 90 days - 6 hours Last 28 days - 2 hours
Information Source:	AAIB Field Investigation

Synopsis

The aircraft was carrying out an aileron roll at low level during a flying display when, at an angle of bank of 107° to the left, the nose attitude dropped relative to the horizon. The pilot reversed the direction of roll but also applied a large pitch input which increased the rate of descent, and caused the aircraft to depart controlled flight and impact with the terrain. The accident was not survivable.

It was concluded that the situation was recoverable until the application of the pitch input.

Three Safety Recommendations are made on: minimum aerobatic heights; managing the risk of loss of aircraft control; and medical examination requirements for pilots of high performance aircraft.

History of the flight

Preparation, departure and transit to the display site

On 1 August 2015, G-TIMM was one of two Folland Gnat T Mk 1 aircraft booked for a flying display at Oulton Park, Cheshire. The aircraft used Hawarden Aerodrome (EGNR), 13 nm to the west of Oulton Park, as a forward operating base. Prior to departure from Hawarden, the pilot of G-TIMM, who was the formation leader, contacted the Flying

Display Director (FDD)[1] for a final briefing and discussion which included reference to the display line[2] depicted in the Display Pilots' Notes[3] (Figure 1).

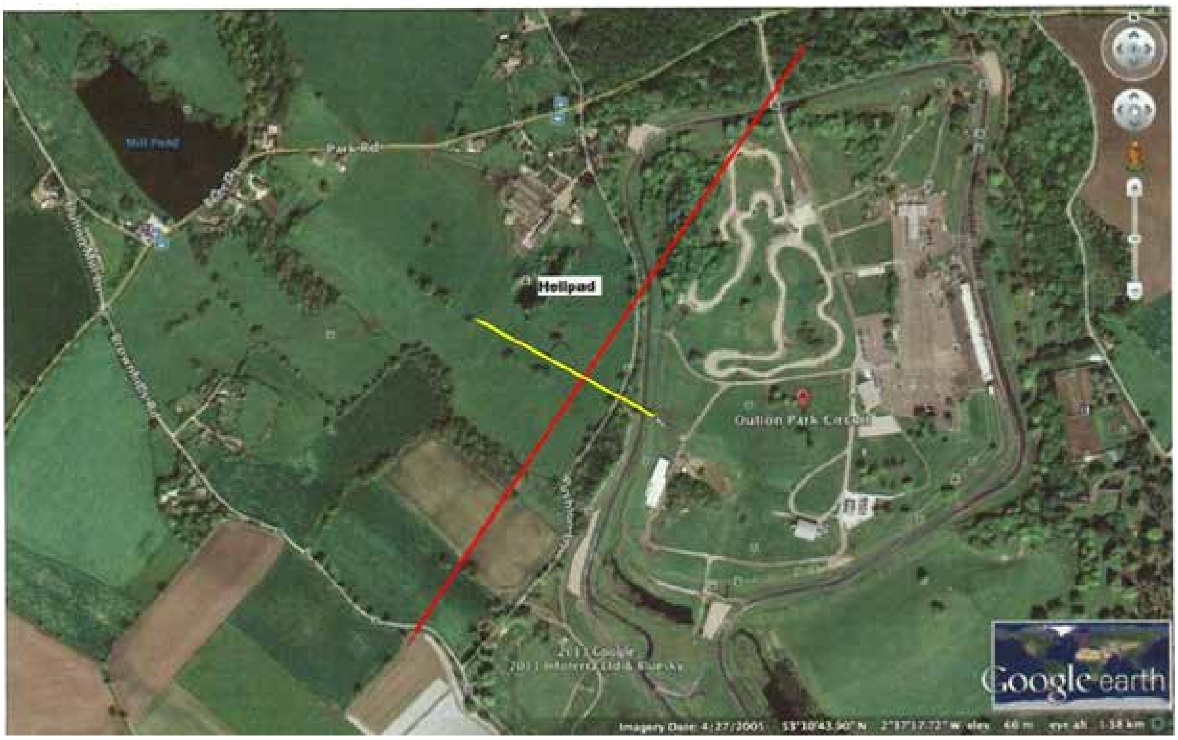

Figure 1

Display line depicted in the Display Pilots' Notes
(Display line in red and display datum line in yellow)

The pilot also contacted Liverpool ATC by telephone before departure because the formation would need clearance to enter controlled airspace during the display and he wished to explain his intentions in advance. Figure 2 depicts the local airspace around the display site.

The formation departed from Runway 22 at Hawarden at 1243 hrs. After departure, the formation contacted Liverpool Approach on 119.850 MHz and was immediately instructed to contact Liverpool Director on 118.45 MHz to obtain a Traffic Service[4]. After contacting Liverpool Director at 1247 hrs, the formation was instructed to remain clear of controlled airspace until the controller had coordinated entry clearance with Manchester ATC, so the aircraft remained in the vicinity of Beeston Castle Visual Reporting Point (VRP).

Footnote

1 See later sections: CAP 393 *Air Navigation: The Order and Regulations*, and CAP 403 *Flying displays and special events: A guide to safety and administrative arrangements.*

2 See later section: CAP 403 *Flying displays and special events: A guide to safety and administrative arrangements.*

3 See later section, Information from the Flying Display Director.

4 A Traffic Service is a radar-based air traffic service where a controller provides information to assist pilots in avoiding other traffic.

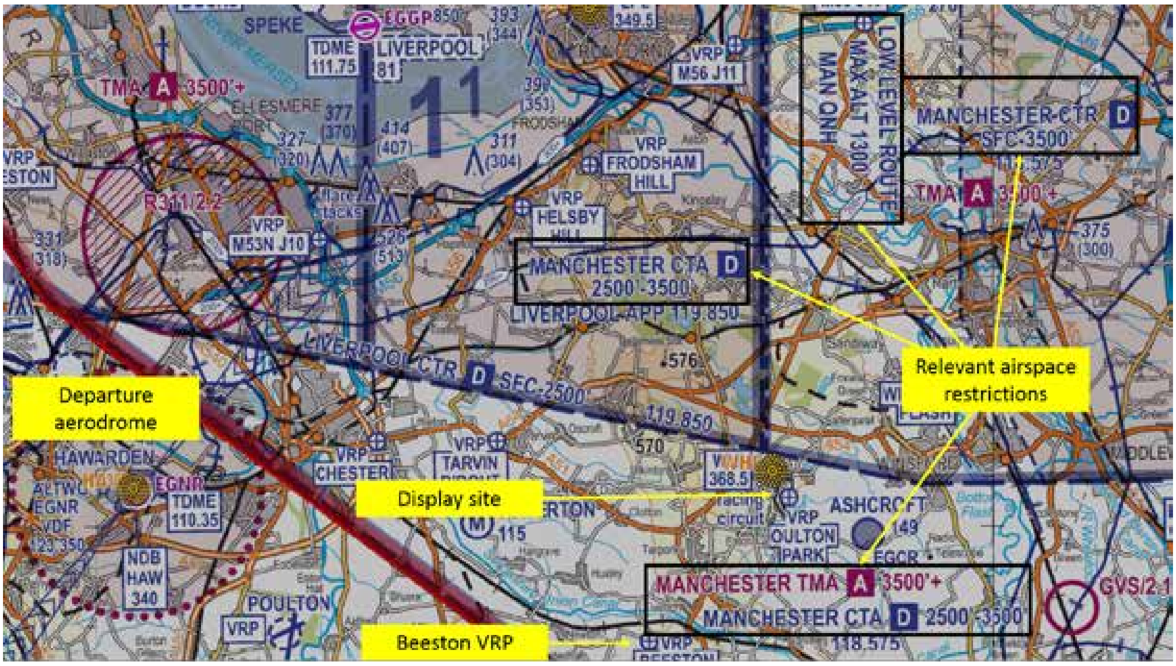

Figure 2

Airspace surrounding the accident site

At 1253 hrs, the Liverpool Director cleared the formation to enter controlled airspace, not above an altitude of 3,000 ft on the Liverpool QNH of 1013 hPa. The clearance was acknowledged by the pilot of G-TIMM who told the controller that he would switch to the display frequency (130.675 MHz) but would listen out on the Liverpool frequency at the same time.

The display

The METAR issued at 1250 hrs by Hawarden stated that the wind was from 240° at 17 kt, the visibility was more than 10 km, there was scattered cloud at 3,500 ft agl, a temperature of 19°C and a QNH of 1013 hPa. When cleared to commence their display by the FDD, the formation was told that the QFE at the site was 1005 hPa and the leader instructed the formation to use this pressure setting as the altimeter height reference.

The formation approached the display site from the south-west (from the left as seen by the crowd) and commenced the display which was planned to be a series of manoeuvres flown in close formation followed by a series of coordinated manoeuvres flown as individual aircraft. The first part of the display was uneventful and the formation split into two individual aircraft as planned. As part of his individual display, the pilot of G-TIMM positioned his aircraft so that he could fly along the display line from crowd left while rolling the aircraft about its longitudinal axis. The aircraft completed one 360° roll to the left, beginning and ending with the wings level, and, after a pause of less than a second, began to roll to the left again. As the aircraft reached 107° angle of bank, the nose of the aircraft dropped relative to the horizon, following which the pilot reversed the roll control input and the aircraft began to roll to the right. Approximately 0.2 seconds after the aircraft began rolling right, there was a marked pitch[5] input which lowered the nose attitude further relative to the horizon and increased the rate of descent. The aircraft struck the ground, approximately 4.3 seconds after commencing the second roll to the left[6].

Accident site

Examination of the accident site indicated that the aircraft initially struck trees of a height of approximately 80 feet whilst in a steeply descending flight path at a relatively low forward speed. The small size and cross section of the aircraft relative to the spacing of the tree trunks made it unclear as to the attitude of the aircraft at initial impact, but the overall site, bisected by a road, was compact.

With the exception of the rear fuselage, the tail surfaces, the majority of the wing structure, the three landing gear units and the combined engine and jet-pipe, the aircraft was grossly fragmented. This was probably because of the light construction of the forward and intermediate fuselage compared with that of the wing structure.

Owing to the age of the aircraft and because the aircraft manufacturer who designed and manufactured the ejection seat is no longer in existence, little knowledge of the ejection seat design was available to the investigators at the accident site during the 24 hours following the event. Lack of information detailing the general layout of the ejection seat, and the position of the various explosive cartridges[7], prevented early identification of the fragmented and burnt components of the seat. It was known however, that the aircraft normally flew with the front ejection seat armed and the unoccupied rear ejection seat unarmed but with live explosive cartridges in place. Live ejection seats present a hazard to those who work around them and, following the accident, this hazard presented a high risk of injury to the first responders and to accident investigators.

Eventually, the engineer who routinely serviced the seats in G-TIMM and other Gnats for the aircraft operator, travelled to the site and was able to examine the wreckage. He confirmed that both ejection seats had been installed at the time of the impact and that the head boxes of both had come to rest in an area of very severe disruption and fire. It was confirmed that main and drogue explosive cartridges from both seats had discharged as a result of heat from the ground fire. The remaining low-powered cartridges, associated with occupant separation, remained, undischarged, in an area clear of fire.

The engineer referred to above was thought to be the only person in the UK with the appropriate expertise to respond to an accident involving the type of ejection seat fitted to the Gnat.

Footnote

5 An aircraft pitches (rotates) about its lateral axis. Pitch control inputs are made by forward and aft movements of the control column which vary the position of the tailplane relative to the airflow.

6 See later section, Aircraft flightpath and control inputs, for an in-depth description of the flightpath.

7 A cartridge is a container of solid fuel or propellant, with self-ignition system, for propulsion by supplying pressure to a one-shot system.

Information from the Flight Display Director and flying display organiser

Approximately three months before the event, the organisers of the display provided the FDD with a document, *'Display Pilots Notes'*, which he was told by the display organiser contained information approved by the CAA for previous flying displays at the same site. This document, which included the display line shown in red in Figure 1 and an image of overall site activity shown in Figure 3, was sent to the operator.

An *Application for Flying Display Notification*, dated 4 July 2015, was sent to the CAA General Aviation (GA) Unit noting that the only change from previous applications was in respect of the FDD. On 27 July 15, the CAA issued a Permission under Article 162 of the Air Navigation Order (ANO) approving the FDD's appointment. One of the conditions of the Permission, however, was that the display line should be amended, in accordance with Schedule I to the Permission, as shown in Figure 4. The FDD saw the document for the first time during the evening before the event and realised that it required display pilots to avoid a farm (shown as an amber box in Figure 4). The following day, before the display began, the FDD contacted the occupants of the farm who confirmed that they would be attending the event at Oulton Park and that the buildings would not be occupied during the flying displays. The display organiser commented that this was the fourth annual show and an agreement was in place to ensure that the farm buildings were unoccupied between 1130 and 1300 hrs UTC. The north-west corner of the show site was also to be unused while display flying was taking place.

Figure 3

Overall site activity and enclosures

Figure 4

Amended display line from the CAA Permission

During their conversation before the formation left Hawarden, the FDD and pilot of G-TIMM discussed the fact that there was rising ground along the display line, from left to right as viewed from the crowd, and the FDD told the pilot where the display datum would be marked. He also instructed the pilot not to fly further east of a line, shown in yellow in Figure 5, which was parallel to the display line shown in the Display Pilots' Notes. Figure 5 also shows the display line in the CAA Permission, the location of the accident site, a camping site and a car park for day visitors to the show. The camping site and car park were expected to be inaccessible during the flying display, and the organiser stated that security staff had been briefed accordingly. He reported that he contacted Event Control on the radio just before the display to remind them of this requirement.

Information from the pilot of the second Gnat

The pilot of the second Gnat did not see the accident because it happened behind his aircraft but he stated that the pilot of G-TIMM gave no indication that anything was wrong at any stage of the flight.

Before the flight, the pilots realised that their display would take them outside the temporary restricted airspace (RA(T)) that had been created for the event[8], which had a radius of 1.5 nm and a vertical limit of 2,500 ft amsl. They decided that, because their display would take them into Class D airspace, the pilot of G-TIMM should discuss their requirements with Liverpool ATC before departure. They decided to use a display line, displaced north-west of the display line shown in Figure 1, passing through the farm buildings shown in Figure 6. The orientation of the buildings, ie parallel with the display

Footnote

[8] The airspace was restricted by The Air Navigation (Restriction of Flying) (Oulton Park) Regulations 2015 made on 4 June 2015 and in force on 31 July 2015.

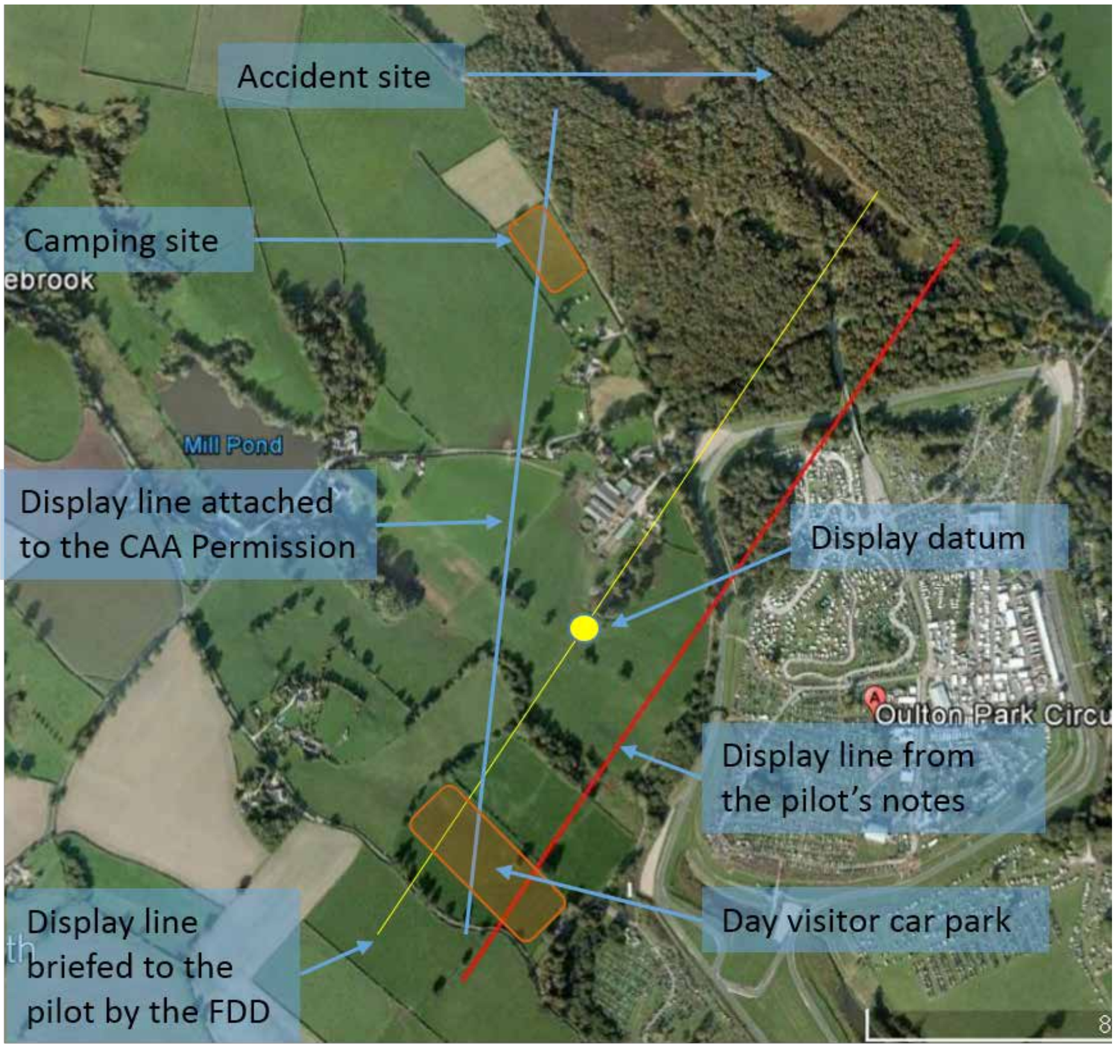

Figure 5
Display line briefed to the pilot of G-TIMM

line, made them a good feature to use from the air. Figure 6 also shows the location of a camera which recorded the accident and two witnesses who were standing in the car park referred to earlier. A tree, the relevance of which is discussed in the next section, is also highlighted in Figure 6.

The pilot of the second Gnat stated that, at the time of the accident, the pilot of G-TIMM would have been performing 'twinkle' rolls along the display line. He expected him to have flown a minimum of two rolls but a third would have been flown had it been necessary to position the aircraft correctly within the display. 'Twinkle' rolls would be flown at approximately 300 kt IAS and would begin with a nose attitude of approximately 3° above the horizon to allow for a drop in attitude of about 2° during the manoeuvre.

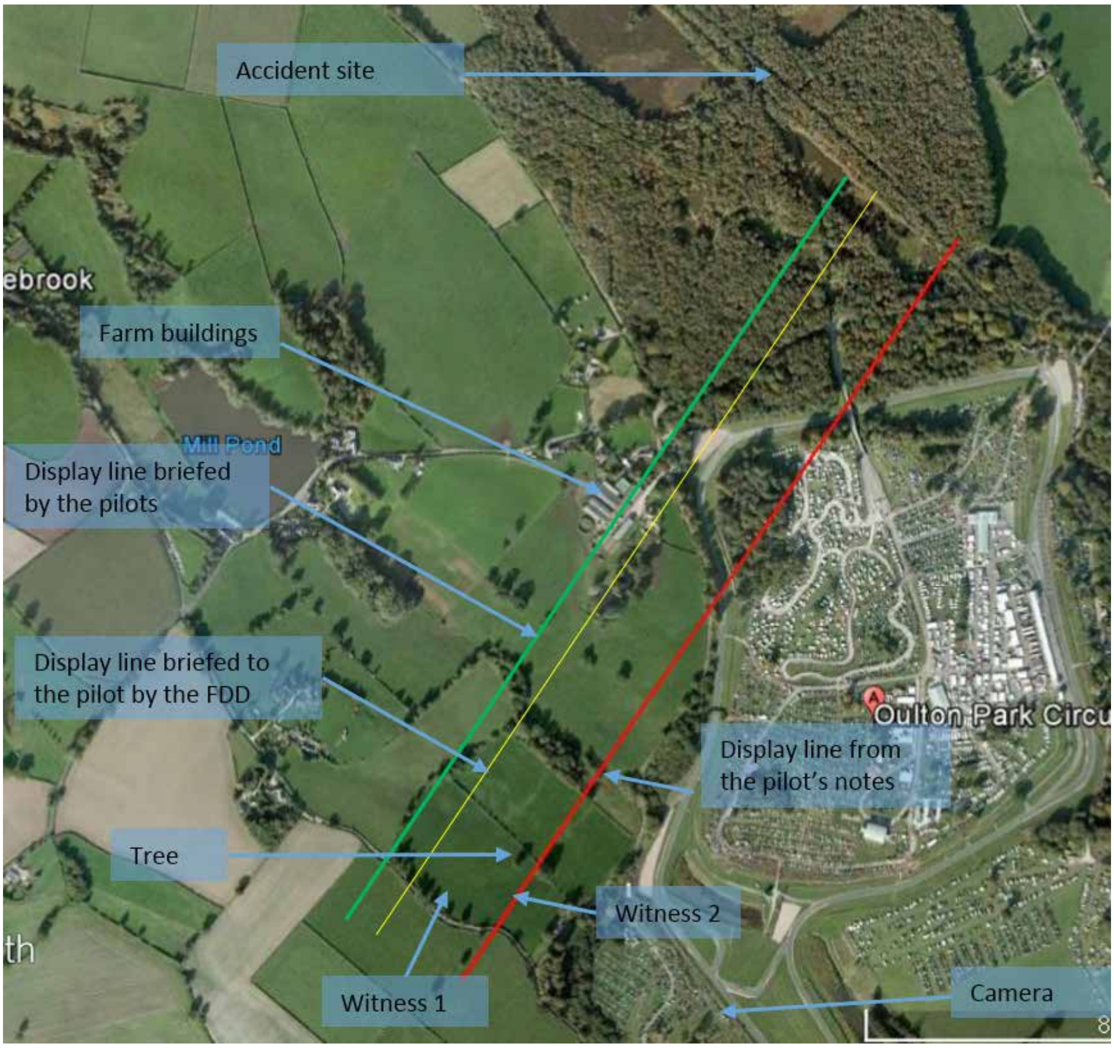

Figure 6
Display line briefed by the pilots

Information from witnesses

Witnesses 1 and 2 reported their location as shown in Figure 6. Witness 1 took the image shown in Figure 7 and stated that G-TIMM flew "directly overhead" as it began its final pass.

Figure 7 (right)
Image taken by Witness 1

Witness 2 took the image shown in Figure 8. He stated that "G-TIMM did not fly directly overhead … but further to the west of my position, and indeed, from the angle of the photos, some way to the west". The tree in the image is marked in Figure 6.

Figure 8 (right)
Image taken by Witness 2

Aircraft description

General

The Folland Gnat T Mk1 aircraft was formerly a military advanced trainer developed from an earlier Gnat light fighter design. The fighter was originally designed to be the smallest aircraft capable of fulfilling the single seat interceptor mission and, as developed into a two-seat trainer, was unusually small and light compared with other aircraft performing in that role. Consequently, the fuselage structure in particular employed lighter gauge panelling and needed to be less substantial than other, physically larger, aircraft designed and stressed to operate within a comparable flight envelope. The longitudinal strength and stiffness of the fuselage was partly dependent on the more substantial wing structure.

Controls

Flight control is normally by means of ailerons, rudder and an all-moving tailplane. Aileron movement is achieved by means of a cable and quadrant system within the forward and centre fuselage, and tubular push-pull rods situated in the wing leading edges, forward of the front spar. This system operates hydraulic servodynes, the bodies of which connect directly to the corresponding aileron drive rod. Tailplane movement is also achieved via cables and quadrants in the forward and centre fuselage, driving rods and levers in the rear fuselage connected to a two-way operating valve of an Integral-Beacham hydraulic motor. Hydraulic flow and pressure are supplied to the servodynes and the motor by a single engine-driven pump.

The tailplane hydraulic motor drives a gearbox situated within a special dedicated 'Hobson' unit. The latter incorporates two screw-jacks, both the outer elements of which are rotated by the gearbox system within the unit. Consequently, the inner threaded elements of each either extend or retract, depending on the direction in which the valve opens and the consequent direction of rotation of the motor. The aft end of the left inner screwjack drives a bellcrank on the left tailplane, whilst the right component provides a similar function to the right tailplane. The Hobson unit thus drives the tailplane halves and ensures they remain synchronised. Longitudinal trim is carried out via an electric motor driving an idler gear within the gearbox of the Hobson unit, whilst another idler gear drives a dedicated screwjack which in turn drives a rod, external to the gearbox, connected geometrically to the operating valve of the motor. Thus a feedback system is achieved whereby commanded selection of the valve on the motor to an open position causes the gears, screwjacks and tailplanes to move until consequent stroke of the rod shuts the valve and movement of the system and the tailplanes ceases.

Emergency provision

If main system pressure is lost, a hydraulic accumulator supplies short duration pressure via separate supply pipes to the aileron servodynes. A dedicated accumulator performs a similar function for the tailplane hydraulic motor, following hydraulic system failure. Such a hydraulic failure would be followed by a cockpit warning requiring the pilot to reduce speed, level the aircraft using the pressure and flow supplied from the accumulators and to use the normal pitch trim system. Thereafter it is necessary to operate a manual plunger on the upper left side of the instrument panel. This unlocks the pair of elevators, which in normal flight are locked to the tailplanes. These then operate without hydraulic assistance, responding to normal control column pitch inputs. Following loss of pressure, the tailplane is maintained at its final hydraulically driven position by the application of a brake within the Hobson unit which functions automatically once hydraulic pressure is lost. Following such loss of pressure, the ailerons operate manually with the control inputs acting on the bodies of the inactive servodynes. Manual control can only be fully effective at speeds below approximately 300 kt.

Escape system

The ejection seats of the Gnat were designed and produced by the aircraft manufacturer. The seats utilise only explosive cartridges, rather than a combination of cartridges and rockets that are used on most modern seats. The main and drogue cartridges are mounted in the head-box of each seat.

Normal operation is by handles on the head-box, which cause the canopy to release followed by ejection of the seat. A secondary method of ejection is by means of a seat pan handle which only operates the seat. The canopy must be manually released before the seat pan handle is operated although canopy breakers mounted above the head-boxes can destroy the transparency of the canopy as the seat exits the aircraft.

Power unit

The aircraft was powered by a single spool turbojet engine with an axial compressor.

Detailed examination

Airframe

Detailed examination of the wreckage at the AAIB indicated that all extremities of the aircraft, all flying control surfaces (including flaps) and the main landing gear doors (also acting as airbrakes) were present. Both underwing slipper tanks had clearly been correctly mounted at the time of impact. Sufficient fragments of the canopy structure and transparency were present to indicate that the latter remained secured to the aircraft at impact.

Flying controls

Since the flying controls were largely cable operated, passing through the destroyed cockpit and midships section of the fuselage, it was not possible to establish their integrity. The wing leading edge structure was destroyed during the impact and a significant proportion of the tubular aileron operating rod system housed within was fragmented and not identified. A number of other mechanical parts were also too fragmented to be identified. Examination of the mechanical section of the tailplane control in the remains of the rear fuselage revealed no evidence of any pre-impact failure. X-ray and strip examination of the hydraulic motor and the Hobson unit revealed that the brake assembly in the latter had correctly functioned following loss of pressure and there was no evidence of any form of failure in the internal parts of either component. The links from the screwjacks to the tailplane operating bellcranks were still connected and the latter correctly attached to their respective tailplane halves. The nature of the damage rendered it impossible to determine whether the elevators had been locked to their respective tailplane halves at impact.

Engine

Examination of the engine revealed no evidence of pre-impact failure. Although the compressor casing remained in a damaged but not totally destroyed state, with the exception of those on one stage, all compressor blades were absent, each having separated at the root. The remaining blades on the single stage were all severely distorted and damaged in a manner consistent with operation at high speed whilst in contact with the casing, or following blocking by debris whist rotating at high speed. The turbine casing was only lightly distorted but all turbine blades had been bent in a manner consistent with high rpm operation at the time the casing distortion occurred.

Impact and fire damage to the fuel control unit and other engine ancillaries precluded any useful further examination.

Ejection seats

The bulk of the remains of the ejection seats were identified in the wreckage although it was not possible to distinguish between the upper sections of the occupied front seat and those of the unoccupied rear seat. The seat remains were extensively damaged by impact and, in the separated upper parts of the seats, by fire. The condition of the seat structure within the mounting tubes and of the main and drogue cartridges (situated in the head boxes) was consistent with the consequences of the impact followed by the fire, ie all upper cartridges had completely discharged and the inner seat rails had remained fully engaged in the mounting tubes following the impact bending of both inner and outer tubes on both seats. Most of the canopy frame was recovered from the wreckage site as was a significant proportion of the transparency. Cartridges in the lower parts of the seats, associated with seat separation, had not fired. It was concluded that the canopy had not been released and neither seat had moved up its mounting tubes. These findings were consistent with the pilot having made no attempt to eject.

Pilot information

Licence

The pilot of G-TIMM held a Private Pilot's Licence (PPL) issued by the CAA under European licensing regulations. The licence was endorsed with a Single Engine Piston (SEP) (land) Class Rating valid until 31 January 2017. The pilot held an Exemption from the requirement to hold a Type Rating for the Folland Gnat T Mk 1[9] valid until 25 June 2016.

The pilot held a Display Authorisation (DA) issued by the CAA, valid until 26 May 2016, which permitted him to take part in flying displays in accordance with terms contained within the DA as follows[10]:

1. Type of aircraft: Single engine jet aircraft (Gnat; Jet Provost).
2. Minimum height for flypasts: 100 ft.
3. Aerobatic category: Standard
4. Minimum height for aerobatics: 300 ft.
5. Formation flying: Advanced formations with unlimited numbers of aircraft.
6. Tailchase flying: Advanced tailchases with up to four aircraft, flying as the leader or as a member of the formation.

General background and experience

The pilot began flying training with the RAF in December 1995 in the Bulldog T Mk 1, a single engine piston aircraft, and flew 110 hours in the period until August 1999. He then undertook training on the Tucano T Mk 1, a single engine turbo-prop aircraft, flying 148 hours between September 1999 and June 2000.

The pilot passed his PPL(A) SEP skills test in January 2003 and, in the same month, began training on the Jet Provost, a single engine turbine aircraft, flying 65 hours on that aircraft in the period up until December 2004. He first flew the Gnat in April 2005. A summary of the pilot's Gnat and Jet Provost flying since 2005, taken from his flying logbook, is shown in Table 1.

The pilot flew his last flight of the 2014 display season in a Gnat on 13 September 2014. His next flight, flown in a Cessna 152 to revalidate his PPL SEP (land) Class Rating, took place on 31 January 2015. On 25 April 2015, the pilot flew his annual currency flight in the Gnat, supervised by a DA Examiner (DAE) in the rear seat, during which he practised his solo display. Later that day, the pilot flew as number two in a three-aircraft formation display practice with a different DAE in the rear seat. On 26 April 2015, the pilot flew as number two in another three-aircraft formation display practice with one DAE leading the formation and another DAE in the third aircraft. The pilot's DA was renewed following the third flight, and he subsequently flew displays on 2 and 3 May, 28 June, and 23 and 30 July 2015.

Footnote

9 The Air Navigation Order (ANO) requires a pilot to have a valid Type or Class Rating to act as pilot of a particular Type or Class of aircraft. The Gnat is not classified as a particular Type or Class of aircraft and an Exemption to the requirements of the ANO is required before a pilot can fly the aircraft.

10 The framework within which display flying takes place is discussed later in this report.

Year	Number of flights	Hours flown		Displays or practices		Total Time
		Gnat	JP	Gnat	JP	All types
2005	37	24	4			441
2006	45	24	17	1	12	484
2007	55	33	17	6	14	549
2008	30	31		12		589
2009	46	32		31		627
2010	24	15	1	13	1	645
2011	11	6		5		652
2012	15	11		11		664
2013	18	13		13		677
2014	26	19		18		697
2015	9	10		7		707

Table 1

Flights, hours, displays and display practices flown by the pilot of G-TIMM

Prior to the accident, the pilot had flown:

a. A total of 707 hours (all types) of which 418 hours were in command.

b. An average of 23 hours per year on the Gnat and JP over the previous 10 years[11].

c. An average of 12 hours per year over the previous five years (flown in an average of 16 flights).

d. 2 hours 10 minutes in the previous 28 days (including 1 hour 15 minutes in the previous two days) and 6 hours in the previous 90 days.

e. One display in the previous eight days; two in the previous nine days.

Medical information

In July 2000, a routine electrocardiogram (ECG) conducted by the RAF indicated that the pilot of G-TIMM had a medical condition, Wolff-Parkinson-White syndrome, which required his Medical Employment Standard to be downgraded temporarily pending further tests. Although the RAF believed that medical intervention would probably allow him to return to flying, no such intervention took place and the pilot did not return to flying duties in the RAF.

On 11 January 2003, the pilot underwent his first medical examination for a Class 2 medical certificate issued on behalf of the CAA. His medical condition was not declared at this

Footnote

[11] The majority of the pilot's flying was undertaken between April and September each year.

examination and an ECG taken at the time showed no indications of its presence. The pilot's family were aware that he had been diagnosed with the condition but were not aware of any historic symptomatic episodes and stated that there had been none recently.

Typical symptoms of the pilot's medical condition include chest pain, rapid heartbeats (palpitations), dizziness, light-headedness, fainting, and shortness of breath. Some people do not experience any symptoms but, in others, episodes can last for seconds to hours and, in rare cases, days with the frequency varying from person to person. When the heart beats with an irregular or abnormal rhythm, there can be a drop in blood pressure which can compromise the supply of blood to the brain. The CAA stated that, if this is combined with circumstances where high acceleration (g) forces are experienced, such as in aircraft during high-performance manoeuvres, g-induced loss of consciousness (G-LOC) is more likely to occur. In addition, high-g manoeuvres can in themselves precipitate the arrhythmias which trigger the symptoms. The CAA also stated that the requirements for the issue of a Class 2 medical certificate, valid for use in display flying, do not include routine ECGs (before age 40) which might have highlighted this pilot's condition.

The pilot stated to the RAF in May 2001 that he had experienced some short episodes of palpitations in the past but had not suffered from blackouts, fainting or sudden incapacitation. His last ECG was the one taken on 11 January 2003 and the next one was due at age 40. At the time of the accident, he held a Class 2 Medical Certificate valid until 24 February 2017.

Recorded information

Three video cameras were recovered from the wreckage of G-TIMM along with two of their micro-SD cards. The micro-SD cards were damaged to an extent that no information could be recovered from them. Two GPS units were recovered from the wreckage but the non-volatile memory unit was missing from one and damaged in the other to an extent that no information could be recovered.

Data from ATC radar stations at St Anne's, near Blackpool, and Clee Hill, Shropshire, contained information relating to the accident aircraft up until it began its last pass. The final data showed the aircraft 0.5 nm from Oulton Park at an altitude of 600 ft based on 1013 hPa, equivalent to a height of 375 ft above the QFE datum which was near the display datum shown in Figure 5.

Aircraft flightpath and control inputs

Video footage of the accident, taken from the camera positioned at the point shown in Figure 6, is presented in a series of pairs of images (Figures 9 to 13) on which the time delay between images is shown in seconds. Because the aircraft was moving, the time delay means that each first image shows the aircraft from a slightly different perspective than does its pair. However, the time delays were short and the distances to the aircraft were estimated to be approximately 800 to 1,400 m[12]. In these circumstances, errors

Footnote

[12] The distance from the camera to the aircraft in each image was not determined. However, the distance from the camera to the farm buildings was approximately 800 m and, to the accident site, approximately 1,440 m.

introduced by the different perspectives were considered to be small enough to discount, especially since the analysis is qualitative rather than quantitative.

G-TIMM approached the display line from 'crowd left' and commenced a roll about its longitudinal axis, and the left image in Figure 9 shows the aircraft attitude at the end of that manoeuvre relative to the horizontal yellow line. The pilot then appeared to increase the attitude of the aircraft prior to commencing the second roll, as shown in the right image in the Figure, although the increase appeared slight on the video.

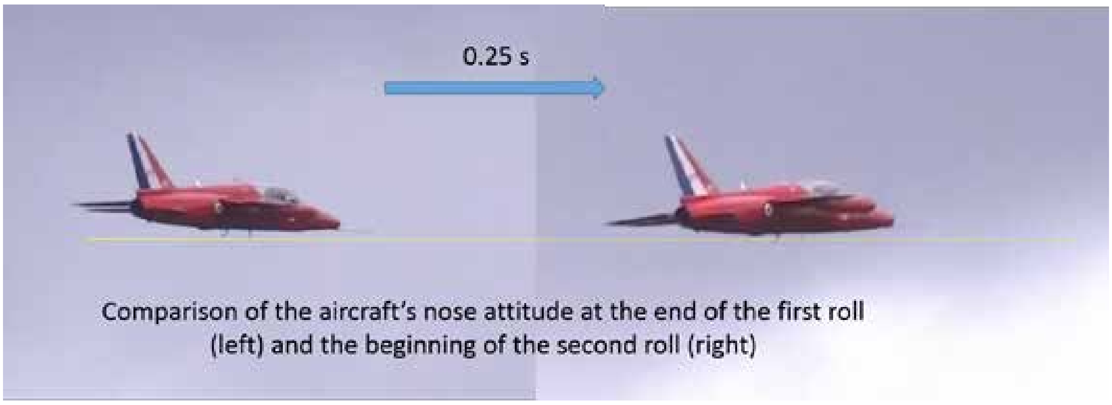

Figure 9

Aircraft attitude before the second rolling manoeuvre

When G-TIMM reached the attitude shown in the left image within Figure 10, the nose attitude dropped relative to the horizon, a drop which was marked on the video. The black lines on the Figure are drawn along a line from the nose of the aircraft through the centre of the jet pipe at its rear to illustrate the drop in nose attitude (shown by the fact that the lines are not parallel).

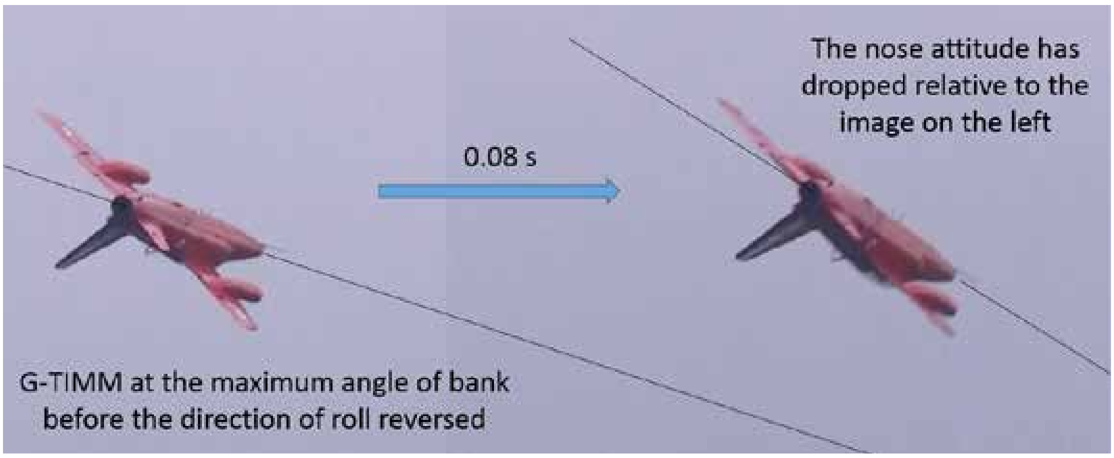

Figure 10

Comparison of the aircraft attitude during the rolling manoeuvre

Immediately after the nose dropped, the direction of roll reversed to the right. Control inputs consistent with this are shown in the left image of Figure 11 by the 'upward' deflection of the right aileron (upward relative to aircraft axes) and, in the right image, by the 'downward' deflection of the left aileron (downward relative to aircraft axes). Approximately 0.2 seconds after the direction of roll reversed, a control input was made to the tailplane whereby its trailing edge moved upwards considerably (upwards relative to aircraft axes). The white lines in Figure 11 are drawn through the leading and trailing edges of the tailplane to illustrate its movement (shown by the fact that the white line in the first image crosses the underside of the aircraft forward of the two aerials whereas, in the second, it passes aft of the two aerials).

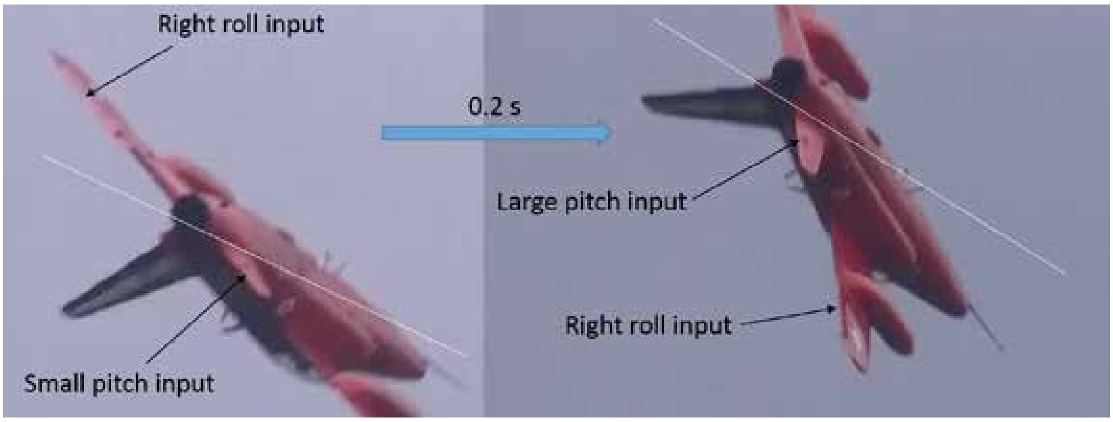

Figure 11

Reversal of roll direction and increase in pitch input

The movement of the tailplane caused the aircraft to pitch (rotate) markedly about its lateral axis. This is shown in Figure 12 by the fact that the first image shows the underside of the aircraft while the second shows its top surfaces. The black lines, once again drawn through the nose and jet pipe, also show the marked change in aircraft pitch attitude.

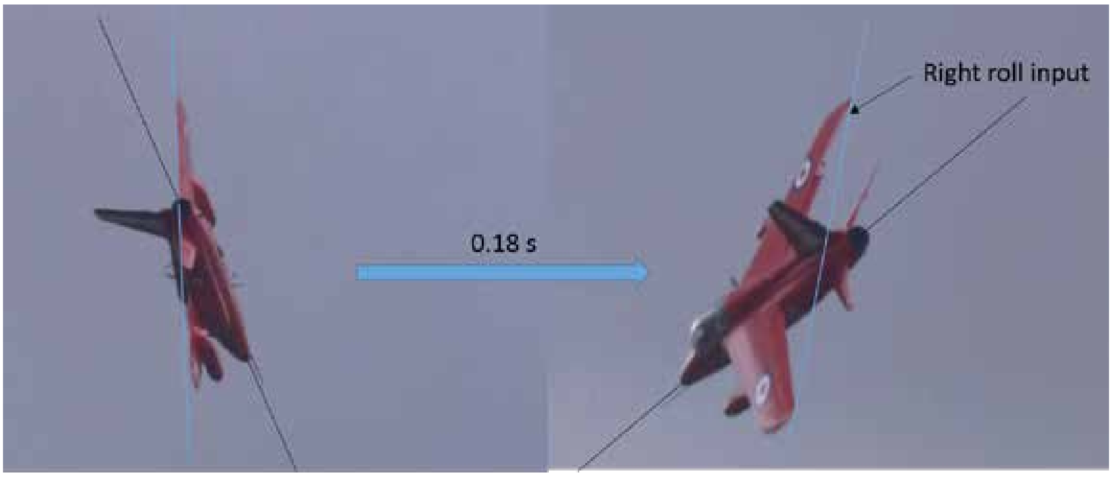

Figure 12

Increase in pitch attitude and reduction in bank angle

The right aileron in the second image is deflected upward indicating that there is a right roll control input. Reference to the blue lines, drawn through the trailing edges of each wingtip, shows that the angle of bank was reducing in response to this input ie the aircraft was rolling right towards a more upright attitude.

Following the marked change in pitch attitude shown in Figure 12, the nose attitude of the aircraft dropped further, illustrated by the fact that the black lines in Figure 13 are not parallel. The right aileron is still deflected upwards, indicating a control input for right roll. However, a comparison of the two blue lines shows that the aircraft was rolling left as it descended towards tree-top height.

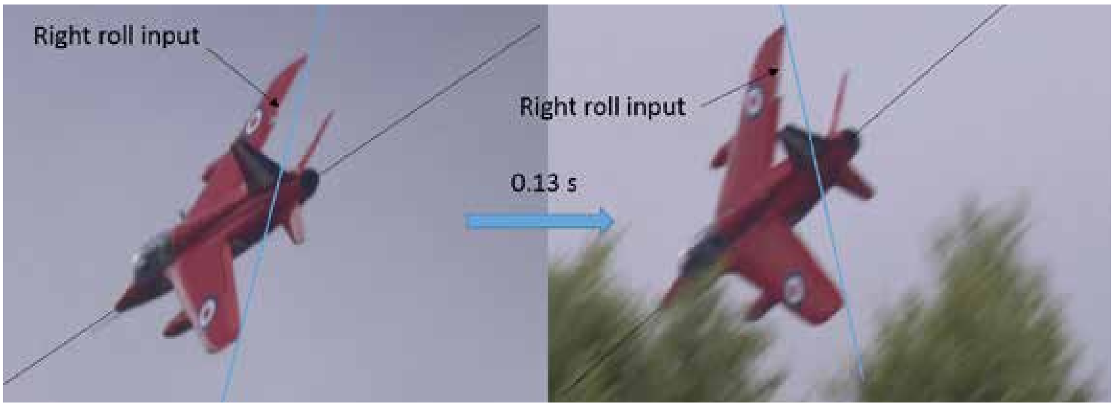

Figure 13

Left roll with right roll control input

Third party flightpath analysis

The video was submitted to the Ministry of Defence (MOD) for analysis. Measurements were made from individual frames with reference to known dimensions of the aircraft, and by matching a 3D computer aided design (CAD) model of the aircraft to sequential images captured from the video. It was not possible to determine the height and attitude of the aircraft relative to the ground from the video evidence but the remaining results, taken from the MOD's report, are presented in Figure 14 and Table 2.

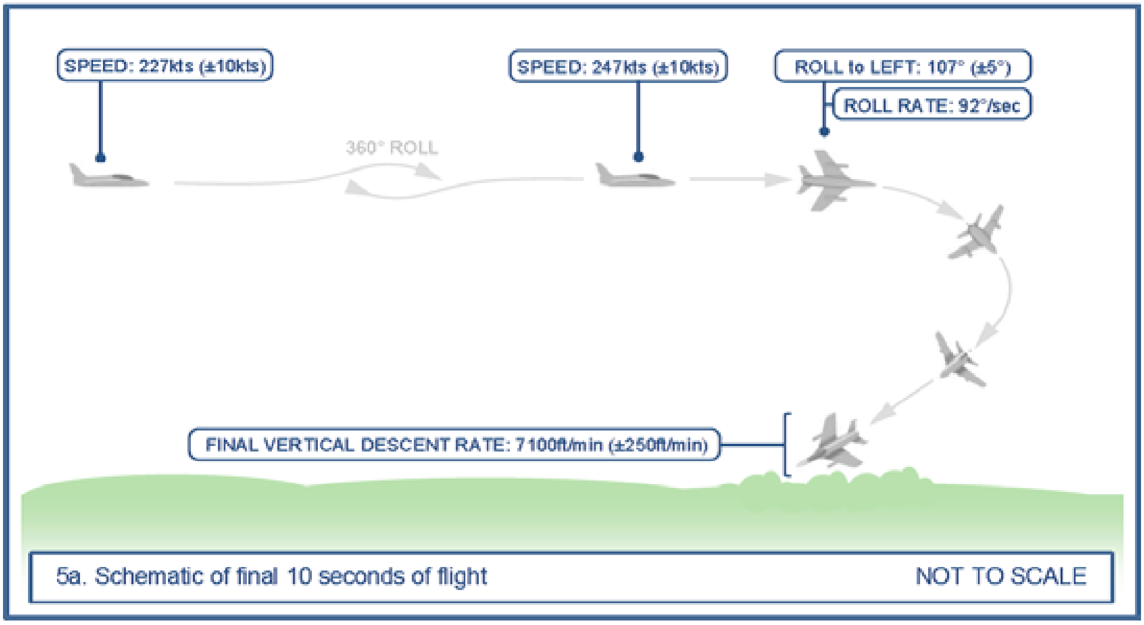

Figure 14

Schematic representation of the final 10 seconds of flight

Event	Measurement
Speed between 10.20 and 9.50 seconds from impact.	227 ± 10 kt
Speed between 5.64 and 5.00 seconds fro impact.	247 ± 10 kt
Roll to left between 4.32 and 3.16 seconds from impact.	107° ± 5°
Roll rate between 4.32 and 3.16 seconds from impact. NB. After 3.16 seconds before impact, the nose pitches down markedly.	92°/s
Vertical descent rate between 0.52 and 0.32 seconds from impact	7,100 ± 250 ft/min

Table 2

Table of measurements

The MOD analysed the still image in Figure 8 and determined that the aircraft was approximately 390 m ± 25 m from the camera used by Witness 2.

The path of the aircraft near the display line

The AAIB and the operator of the Gnat carried out independent analyses of an on-board video recording taken from the second Gnat to establish the aircraft's ground track during the time that G-TIMM was being positioned for its final pass in the area south-west of the display line (Figure 15). The position fixes were established by comparing features on the ground, seen from the on-board video recording, with the same features seen in an overhead view in Google Earth. The associated times were taken from the video and relate to the beginning of the recording. The red and yellow stars represent locations identified by the AAIB and operator respectively.

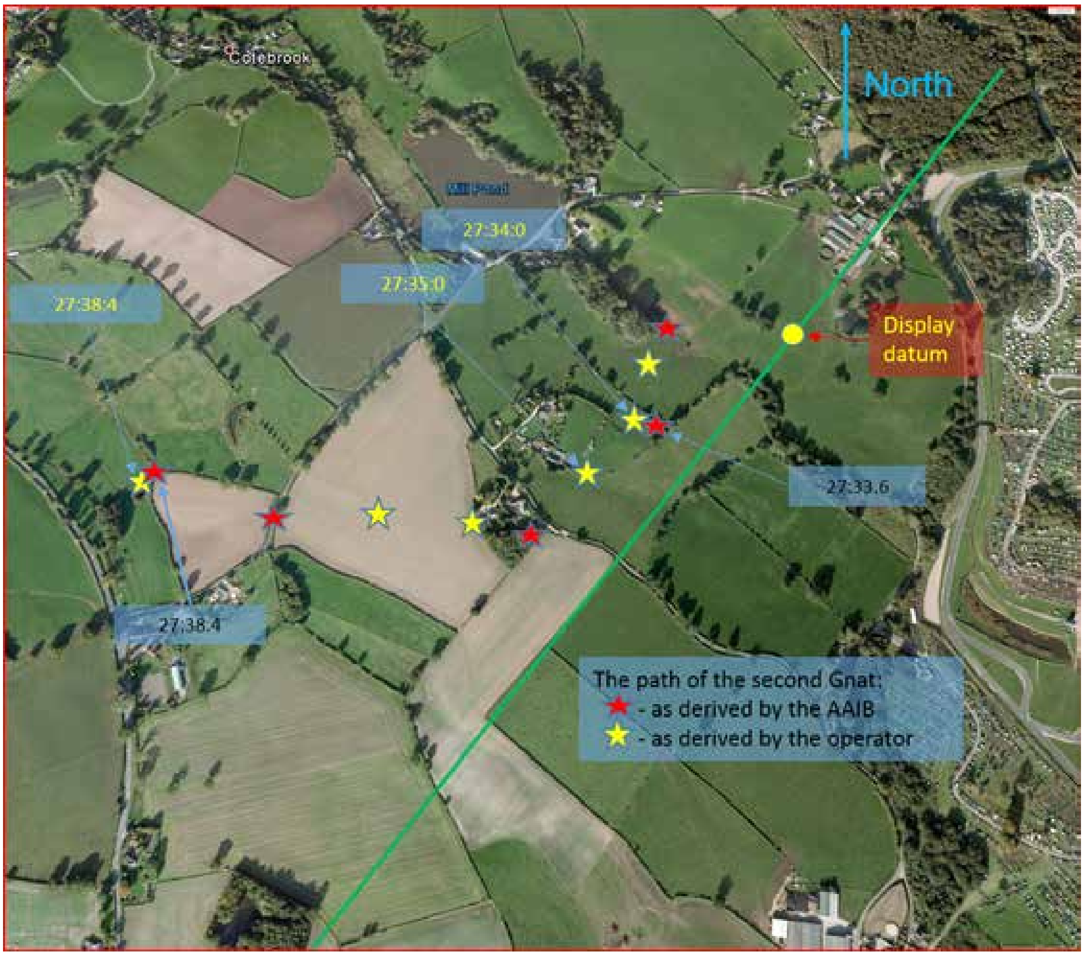

Figure 15

Ground track of the second Gnat

Figure 16 is an image, taken at 27:38.4, of G-TIMM and the second Gnat crossing the line of sight of a ground-based camera (the ground-based camera which provided the video discussed earlier) [13]. At 27:38.4, the operator and AAIB analyses of the second Gnat's

Footnote

[13] Timing between the on-board video and the video from the ground-based camera was synchronised against an aircraft manoeuvre recorded by both systems.

position agree to within approximately 50 m (Figure 17). A line of sight was drawn from the camera's location through the second Gnat's position at 27:38.4[14] and G-TIMM was on this line at this time, although its exact position along the line could not be determined.

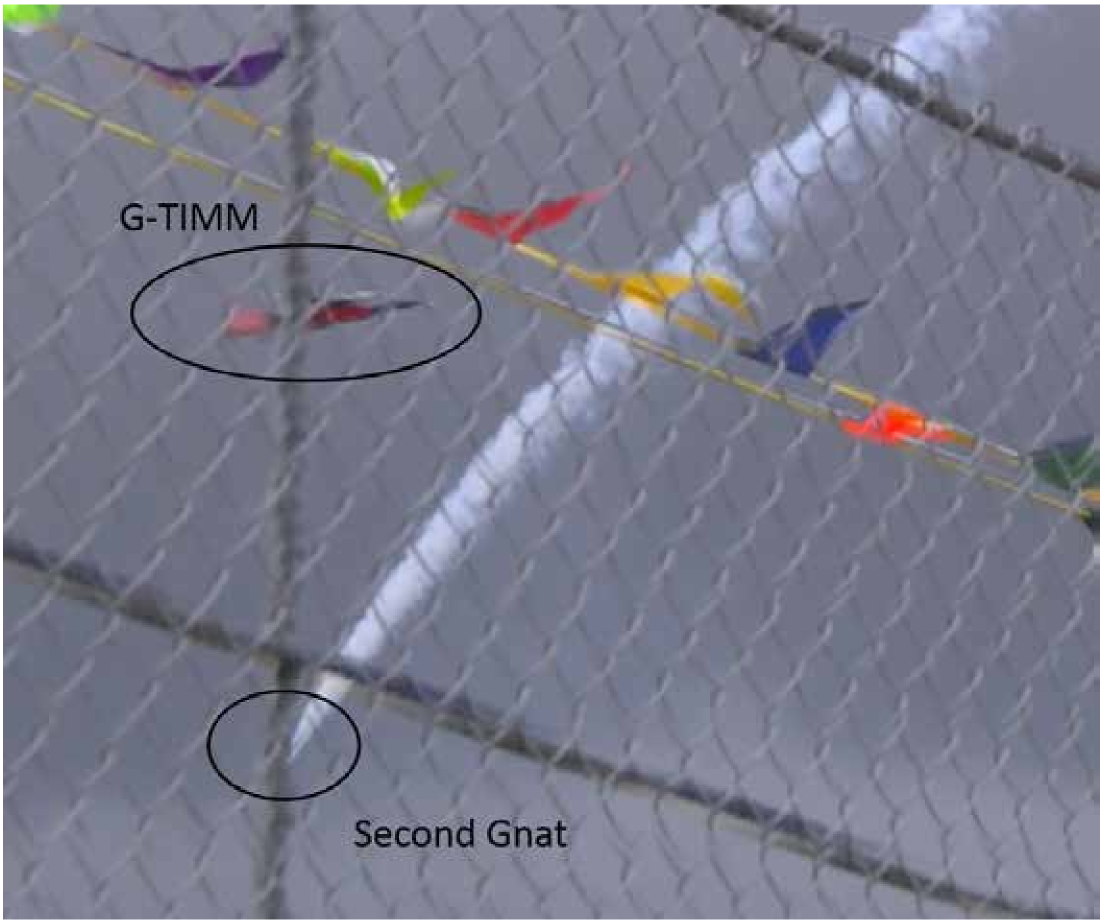

Figure 16

Image of both aircraft at 27:38.4 as G-TIMM commenced its final pass

Figure 17 shows a sight line from the camera of Witness 2 passing the tree shown in Figure 8 and the MOD measured the distance of G-TIMM along this line to be approximately 390 m. Using the last known height of G-TIMM (375 ft above the display datum), this is equivalent to a ground distance of approximately 370 m which suggested that G-TIMM was flying close to the display line (Figure 17). Evidence from Witness 1 suggested that the aircraft's location was bounded by a south-easterly limit shown by the yellow line 'A' in Figure 17.

No quantitative information was available about relative heights of the two aircraft. However, the on-board video in the second Gnat showed that the manoeuvre it flew (described by the points in Figure 15) was flown with vertical extent, and the operator stated that aircraft flying this manoeuvre would typically be between 1,500 and 2,000 ft agl at the apex.

Footnote

[14] The line was drawn through the mid-point between the AAIB- and operator-determined aircraft positions.

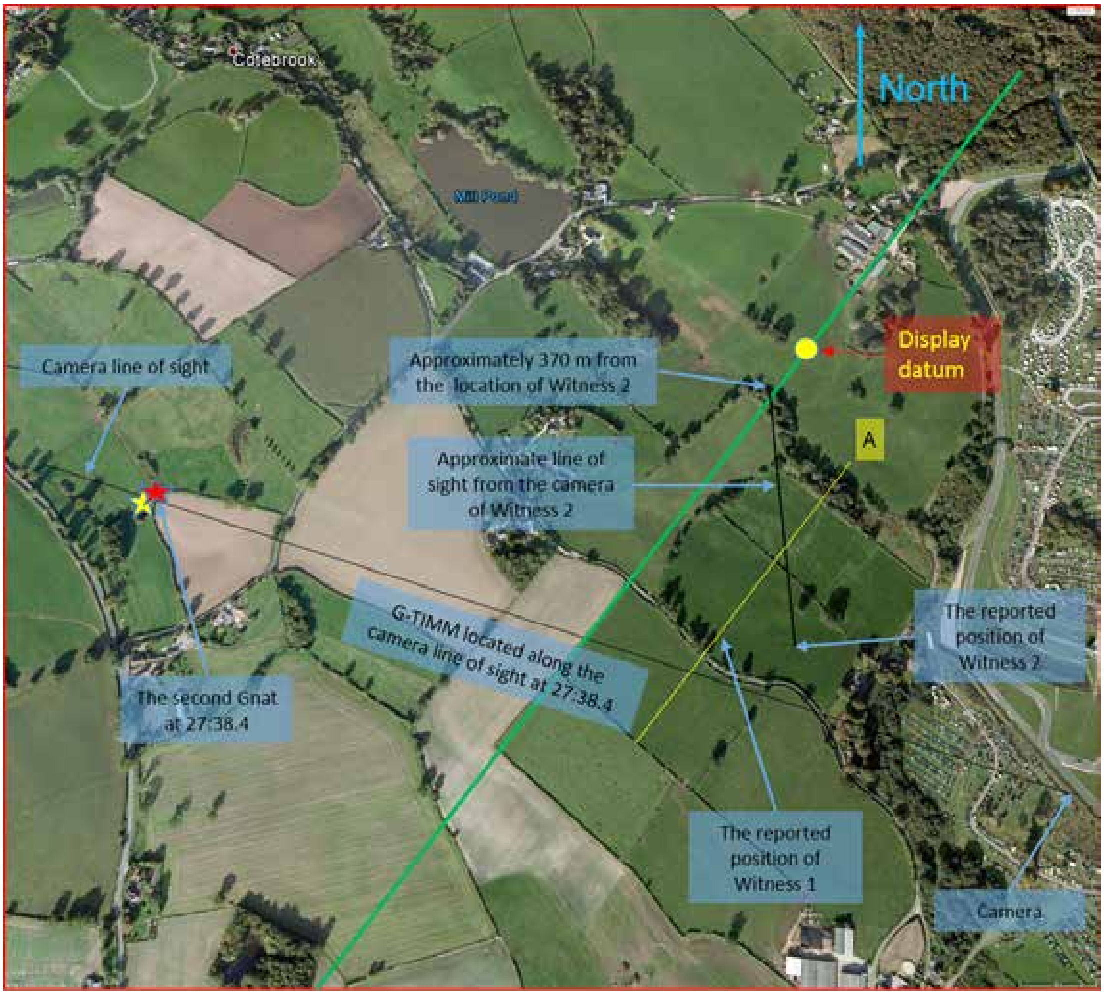

Figure 17
The camera line of sight at 27:38:4

CAP 393, *Air Navigation: The Order and Regulations*

The ANO empowers the CAA to regulate civil flying displays. Article 162 of the ANO states that a person wishing to organise a flying display must obtain permission from the CAA, and the CAA may grant permission subject to any conditions that it thinks fit. The ANO requires the CAA to grant a pilot a DA if it considers the pilot to be fit to hold the authorisation and to be:

> *'qualified by having the knowledge, experience, competence, skill, physical and mental fitness to fly in accordance with the authorisation.'*

CAP 403, *Flying Displays and Special Events: A Guide to Safety and Administrative Arrangements*

CAP 403 sets out the safety and administrative procedures to be followed by organisers and participants at civil flying displays. It sets out requirements for the appointment of a FDD, whom it defines as:

> *'the person responsible to the CAA for the safe conduct of a flying display.'*

The CAP states that car parks to which the public has access during a flying display must be considered the same as the spectator area.

The display line

The display line defines the closest a display aircraft may approach the crowd line. The crowd line is the forward edge of areas intended for spectators and any car park to which the public has access. The display line must be clearly identified but an obvious line feature can be used in the case of off-aerodrome sites.

Minimum distances from the display line to the crowd line are shown in paragraph 3.25 of CAP 403. Minimum distances from the crowd line relevant to this accident relate to aerobatic manoeuvres flown between 200 and 300 kt (requiring a minimum distance of 200 m) and for aircraft flying above 300 kt (requiring a minimum distance of 230 m).

Paragraph 3.28 of CAP 403 states that pilots should:

> *'always regain the display line without infringing the minimum lateral separation distance from the crowd line. Effects of any on-crowd velocity vectors … must be taken into account.'*

Minimum heights

A pilot's DA includes absolute minimum heights for respective manoeuvres but, at off-aerodrome sites, the CAA will normally impose a minimum height of 200 ft. The pilot of the second Gnat confirmed that the display team was using 300 ft agl as a minimum height for aerobatic manoeuvres and 200 ft agl for flypasts.

Liaison with the CAA

An FDD is required to obtain a Permission from the CAA in order to hold a flying display. The application form should reach the General Aviation (GA) Unit at the CAA at least 28 days before the display date, and it should include a 1:50,000 scale map showing the display line and the layout of the spectator enclosure.

Pilot display competency and recency

There are no specific minimum experience requirements within CAP 403 before a pilot can apply for a DA. However, paragraph 5.14 of the CAP gives DAEs guidance on the minimum sensible level of experience required before a DA application should be considered. For fixed-wing aeroplanes, the CAP suggests a total of 200 hours flying including at least 100 hours as pilot-in-command.

Paragraphs 5.33 to 5.36 of CAP 403 state that display pilots are required to have flown a minimum of three full display sequences or practices within the 90 days preceding a demonstration at a flying display. One of the sequences must have been flown in the specific aircraft to be displayed. The CAP emphasises that these are minimum requirements and encourages pilots to practise sufficiently to maintain a sufficiently high level of safety.

CAP 632, *Operation of 'Permit-to-fly' Ex-military Aircraft on the UK Register*

General and technical requirements

G-TIMM was an ex-military aircraft and one of the conditions of its Permit-to-Fly was a requirement for it to be operated in accordance with CAP 632. The CAP is divided into a number of parts covering, inter alia, pilot qualifications, operational requirements and audit procedures. Operators are required to comply with the CAP by compiling an Organisational Control Manual (OCM), agreed with the CAA, detailing how they propose to manage and operate their aircraft. The CAA normally audits operators annually.

CAP 632 encourages operators to develop a positive safety culture in order to achieve high safety standards and recommends that they adopt a Safety Management System (SMS).

Pilot qualification and currency

Pilots applying to fly high performance jet aircraft, such as G-TIMM, are required to have '*appropriate'* flying experience, and training requirements are assessed on an individual basis. Minimum experience levels and training requirements are required to be included in the OCM, as are currency requirements and levels of supervision. The operator is required to keep pilot flying and ground training records.

Guidance on experience requirements to fly jet aircraft

Appendix C to CAP 632 gives guidance on experience requirements for pilots to fly jet aeroplanes although it comments that each pilot must be judged individually. The CAP classifies pilots as:

a. Inexperienced when they have up to 50 hours pilot in command (PIC) post-licence issue.

b. Intermediate when they have between 50 and 450 hours PIC post-licence issue.

c. Experienced when they have over 450 hours PIC post licence issue.

The operator's OCM

Pilot experience and currency

The operator's OCM states that only Intermediate and Experienced pilots will be considered for training on the Gnat. In order to become self-authorising, pilots are required to gain a minimum of 15 hours on type and to have completed the operator's 'Folland Gnat Conversion Training Schedule' to the level of 'Self-authorising'. According to the schedule, this includes a minimum of 30 hours of airborne instruction including four check flights.

Self-authorising pilots remain current on the aircraft having flown a minimum of one flight in the previous 12 weeks. Pilots with more than 100 hours on type (defined as high performance, swept wing aircraft with hydraulically powered flying controls) require a minimum of one flight in the previous six months.

The pilot of G-TIMM was a self-authorising pilot with more than 100 hours on type. He was an Intermediate pilot based on the 418 hours he had logged as PIC[15].

Display criteria

The OCM states that pilots who display the Gnat will do so in accordance with the conditions set out in CAP 403 and within the operational parameters set out in the Gnat T1 Pilot's Notes.

Safety management

The operator of G-TIMM did not have an SMS as part of its OCM although it stated that it used a risk-based approach when formulating provisions within the OCM. The operator had not identified any elevated risk arising from the experience, training or currency of the pilot of G-TIMM.

CAA Audits

The CAA audited the operator of G-TIMM in October 2012 and January 2014 and, in each case, the only findings were Level Two findings[16] on the maintenance of training records.

Management of aircraft separation during a display

The operator stated that, although at the time of the accident there was no manual documenting in one place its formation display procedures, standard procedures were used to manage aircraft separation during displays and were well known by all its pilots. Prior to taking off, pilots discuss the likely effect of wind during the display and how to compensate for it. During the display, pilots use a 'contract' whereby responsibility for safe separation lies with the pilot positioning for his next pass, and a pilot clearing the display line must call "OUT" on the radio before the incoming pilot calls "VISUAL; RUNNING IN"

Footnote

15 Some of the pilot's PIC hours were gained in the RAF before his PPL was issued. This did not affect his classification as an Intermediate pilot.

16 Level Two findings are non-conformities considered to be in need of remedial action. Level One findings are serious non-conformities which require rectification before any further flying takes place.

and begins his pass. Should a pilot judge that he will arrive on the display line before the other aircraft has vacated it, he can delay his aircraft's arrival by reducing speed, or by flying S-turns or a 360° turn to create extra track distance. Should a pilot choose to slow his aircraft to generate separation, he should maintain sufficient speed to fly the following manoeuvre or, otherwise, not fly that manoeuvre. The Pilot's Notes recommends 280 kt as a minimum entry speed for an aileron roll '*until experience is gained',* although it does not record a minimum speed to be used once experience has been gained. The Flying Instructor's Handbook for the Gnat T1 states that slow rolls can be demonstrated at speeds between 250 and 300 kt.

The pilot of the second Gnat stated that, on clearing the display line, he transmitted "[*CALLSIGN*] TWO IS OUT" and recalls hearing the reply "[*CALLSIGN*] ONE IS VISUAL, RUNNING IN".

Safety Action

Following the accident, the operator produced a document, *Gnat Display Team 2-ship Formation Display Procedures/SOPs,* to document in one place the techniques and procedures to be used during flying displays.

The operator commented that it was possible that the pilot mis-read the airspeed indicator and that this led to him flying towards the display line at a speed lower than expected. They also considered the possibility that the pilot of G-TIMM was flying slower than expected because, while positioning for his next pass, he did not displace himself far enough away from the display line. In these circumstances, the pilot might slow down or extend his ground track as described earlier but should not fly below the minimum entry speed for the following manoeuvre.

Equivalent military regulations

The Royal Air Force (RAF) operated the Folland Gnat in the fast-jet training role currently undertaken by the BAe Hawk, and both aircraft are similar high performance jet aircraft. This section considers some of the regulations applicable to RAF display pilots flying the Hawk as a benchmark for further discussion.

Minimum experience

In order to undertake flying displays, an RAF Hawk pilot requires a 'Public Display Authority' (PDA) which is the equivalent to the CAA's DA. Hawk display pilots will be nominated by their Station Commander following a practical assessment of their flying ability, an interview to assess their suitability for display flying, and a review of their flying record. The nomination must be approved by a senior officer in the headquarters of RAF flying training. There are no specific requirements for the minimum number of hours a pilot should have flown. However, most Hawk pilots eligible to display the aircraft will have previously flown at least one front line fast jet tour and will therefore meet the CAA classification of Experienced.

Minimum heights

Hawk pilots develop their display sequence using a minimum height of 5,000 ft. They then fly a minimum of six practices to a minimum height of 1,500 ft before being cleared to use a minimum height of 1,000 ft. Following a minimum of six practices to a minimum height of 1,000 ft, the pilot may be cleared to display down to a minimum height of 500 ft (100 ft agl for flypasts as part of the display).

Display currency

In order to maintain PDA currency, an RAF Hawk pilot is required to have flown two displays or practice displays in the previous eight days using a minimum height of 500 ft.

AAIB Special Bulletins

The AAIB published Special Bulletin S4/2015[17] in relation to the accident to Hunter T7, G-BXFI, at Shoreham Airport on 22 August 2015. The Bulletin discussed the safety of first responders at accidents involving aircraft with ejection seats, the maintenance of ejection seats, and the maintenance of ex-military jet aircraft. AAIB Special Bulletin S1/2016[18], published in relation to the same accident, discussed, inter alia, risk management at flying displays, minimum display heights, and standards for display pilots. Both Bulletins made Safety Recommendations which are relevant in the context of the accident to G-TIMM.

Engineering analysis

The aircraft struck trees at a relatively low forward speed and with a steeply descending flight path; the final pitch and bank angles could not be determined. At the time of impact the aircraft was structurally complete, all control surfaces were present and the underwing tanks were attached. The landing gear appeared to have been retracted.

It was not possible to determine conclusively from wreckage examination whether the elevators were locked to the tailplanes or whether hydraulic power remained available to the tailplanes and ailerons. Figures 9 to 13, however, show synchronised inclination of the tailplanes with no separate deflection of the elevators, and a final tailplane angle considerably displaced in an aircraft pitch-up sense. To achieve this amount of tailplane deflection shortly after the aircraft had been in a flight condition with little tailplane deflection would have required hydraulic pressure to be available. Had it not been available, the hydraulic motor would have failed to respond significantly and the brake in the Hobson unit would have operated, preventing any significant tailplane movement.

The images show aileron deflection consistent with observed aircraft roll direction and expected pilot roll control input, ie towards a wings-level attitude. This indicated that aileron deflection was achieved in response to roll control input, regardless of whether manual or hydraulically assisted power was used. Since the tailplane behaviour was consistent with normal hydraulic operation up to the time the aircraft disappeared from the video, it was probable that hydraulic pressure remained available to the aileron control unit.

Footnote

17 https://assets.digital.cabinet-office.gov.uk/media/5677d6bfed915d144f000000/S4-2015_G-BXFI.pdf
18 https://assets.digital.cabinet-office.gov.uk/media/56e178f240f0b6037900001b/S1-2016_G-BXFI.pdf

The following conclusions were made about the aircraft before impact:

a. The hydraulic system was operating the tailplanes in normal mode with the elevators in the locked position.
b. Aileron deflection was consistent with expected pilot control demand.
c. No evidence was found of pre-impact failure in the flying control system.
d. The engine appeared to have been delivering significant thrust.
e. The canopy had not been released, and the ejection seats had not moved up their mounting tubes.

Analysis of the final manoeuvre

The drop in aircraft nose attitude during the roll

The images in Figures 9 to 14 and the information in Table 2 show that the accident sequence began when, with the aircraft at 107° angle of bank to the left, the nose attitude dropped relative to the horizon (Figure 10). The cause of this change in aircraft attitude was not determined.

Figure 14 shows that the first rolling manoeuvre was flown at 227 kt ± 10 kt, approximately 73 kt below the usual entry speed of 300 kt, and the second rolling manoeuvre at 247 kt ± 10 kt, approximately 53 kt slower than the usual entry speed. These speeds were below the recommended minimum speed of 280 kt (although the Pilot's Notes suggested that pilots with experience could fly aileron rolls at unspecified slower speeds). Aircraft rolling at lower speeds have an increased tendency for the nose attitude to drop during the manoeuvre and, if this is not anticipated, it can lead to a lower-than-normal nose attitude at the end of the roll. This can influence the following manoeuvre especially if, as video evidence suggested in this case, the nose attitude was raised only slightly ahead of the second roll. A lower-than-normal nose attitude at the beginning of the second roll, combined with a speed still below the recommended minimum, might account for the drop in nose attitude during the manoeuvre. However, other possibilities for the drop in nose attitude could not be discounted, such as disorientation, visual illusion or distraction.

Control inputs after the drop in nose attitude

After the nose attitude dropped, the aircraft could have been recovered to level flight by reversing the direction of roll, rolling back to a wings level attitude and, with the wings level, pitching the aircraft nose up to arrest the rate of descent and regain level or climbing flight. Figure 11 shows that a control input was made to reverse the direction of roll consistent with the pilot recognising the unusual change in attitude and beginning recovery action. Figures 11 to 13 show that the right roll input was present until immediately before impact, and Figures 11 and 12 show that the aircraft initially responded by rolling right.

Figure 11 shows a large pitch input at the tailplane, and Figure 12 shows that the aircraft responded with a large change of pitch attitude. A pitch input was consistent with the recovery action suggested above except that it occurred too soon, with the aircraft nose below the horizon and with an angle of bank greater than 90°. The pitch input rapidly increased the rate of descent and caused the aircraft to depart from controlled flight, shown by the fact that the aircraft began to roll left despite continued right roll control input. The high rate of descent and the departure from controlled flight were each sufficient to make the situation irrecoverable in the height available.

It took 1.16 seconds to roll to 107° of bank and it took a further 3.16 seconds before the aircraft struck the ground. Although the decrease in nose attitude would have caused the aircraft to descend, there was probably sufficient time to roll back to a wings level attitude and arrest the rate of descent before impact. This is because the short time to impact (3.16 seconds) resulted from a rapidly increasing rate of descent (7,100 ft/min immediately before impact) that would not have been present had the aircraft rolled to a wings level attitude. It was concluded, therefore, that the situation was recoverable after the nose attitude dropped during the roll to the left.

Reasons for the lower-than-normal entry speed

The pilot began his first roll approximately 73 kt below the normal entry speed of 300 kt and this was either deliberate or inadvertent. An inadvertent loss of 73 kt represented a large difference from the expected speed and was considered unlikely, although the operator considered that it might have been the result of mis-reading the airspeed indicator. Speed reduction was used by the display team as a method for delaying an aircraft's arrival on the display line (to allow the preceding aircraft to vacate it). Any decision by the pilot of G-TIMM to reduce speed would have been based upon his visual assessment of the progress along the display line of the second Gnat and would have to have been made early enough to have a meaningful effect. For example, an aircraft travelling at 227 kt, as opposed to 300 kt, would have to do so for 16 seconds to delay its arrival at a given point by five seconds[19].

Figure 18 shows the relative locations of G-TIMM and the second Gnat, had G-TIMM arrived on the camera sight line five seconds earlier than it actually did, travelling at 300 kt[20]. Although the Figure shows the outcome of a hypothetical set of circumstances, it suggests that, had G-TIMM not slowed down, the possibility existed that it would have reached the display line before the second Gnat had vacated it. This would have been contrary to the 'contract'[21] used by the operator to ensure safe separation on the display line and, if anticipated by the pilot of G-TIMM, provides a plausible reason for him to slow down. The second Gnat was flying a manoeuvre with vertical extent and it was unlikely that the pilot of G-TIMM perceived that there might be a risk of collision near the display line. Nevertheless, it was possible that G-TIMM was flown slower than usual, at least in part, to delay its arrival on the display line.

Footnote

[19] An aircraft at 300 kt would cover 2,464 m in 16 seconds. Flying at 227 kt, the same aircraft would cover 1,872 m in the same time and would require another five seconds to cover the extra 592 m.
[20] For clarity, the Figure only shows the positions of the second Gnat derived by the operator.
[21] See earlier section, Management of aircraft separation during a display

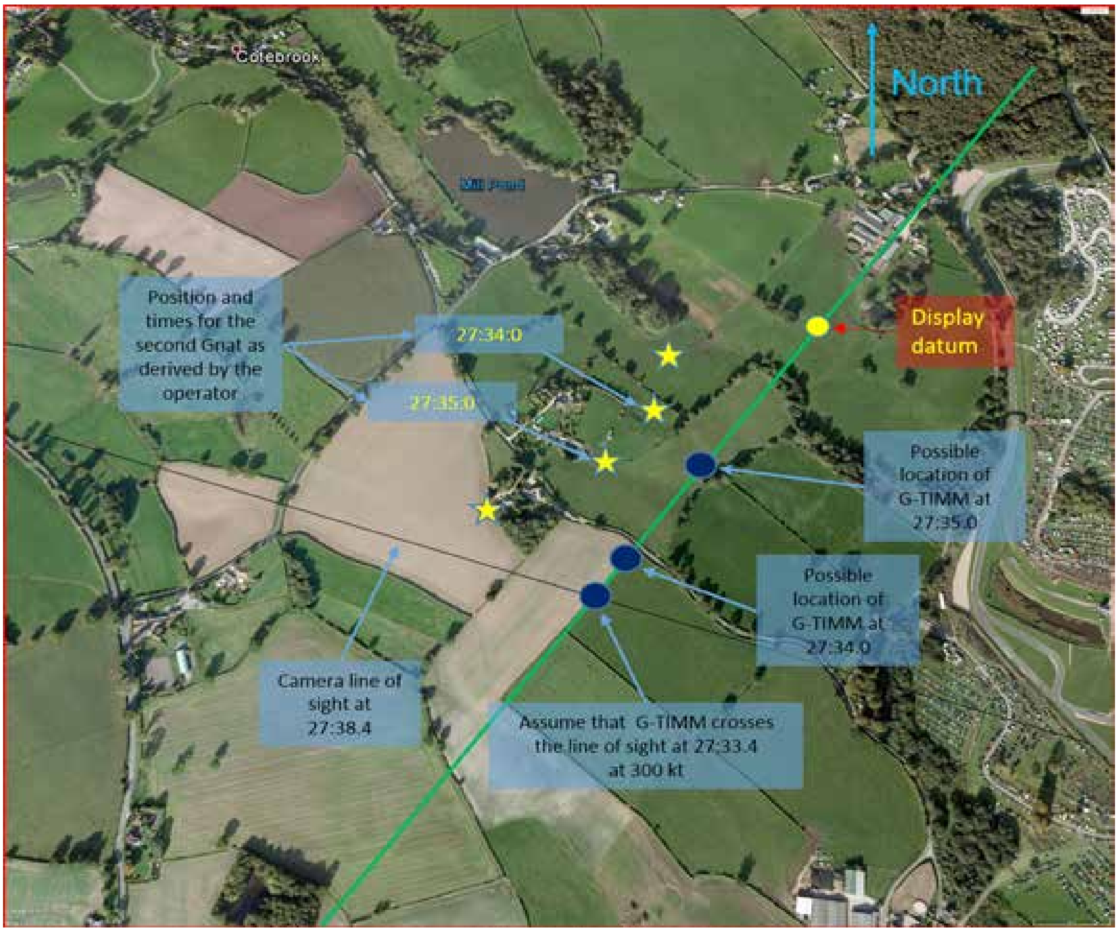

Figure 18

Hypothetical plan view of the aircraft had G-TIMM crossed the camera sight line at 27:33.4

Risk controls

The CAA recommends the use of risk assessment methodologies, such as 'Bowtie' assessments, for the analysis and control of risk within a Safety Management System (SMS)[22] and provides Bowtie templates for its 'Significant Seven' risks to Commercial Air Transport[23]. Bowtie analysis considers measures designed to prevent a 'loss of system control', measures designed to recover control should it be lost, and measures designed to minimise the consequences should control not be recovered.

The following discussion is adapted from two CAA templates: loss of aircraft control and human factors where an activity is not performed to a safe standard. The 'loss of system control' occurs when the aircraft deviates unintentionally from normal in-flight parameters (in this case, the unexpected drop in nose attitude), and the consequence is unrecovered

Footnote

[22] An introduction to Bowtie analysis is available here: https://www.caa.co.uk/Safety-Initiatives-and-Resources/Working-with-industry/Bowtie/

[23] The templates are available here: https://www.caa.co.uk/Safety-initiatives-and-resources/Working-with-industry/Bowtie/Bowtie-templates/Access-the-bowtie-templates/

loss of control and terrain impact. During the discussion, comparison is made with the way the Bae Hawk is operated by the RAF in the display environment as a means of comparing risk control measures.

Risk control measures intended to prevent an unintentional deviation from normal in-flight parameters

The drop in nose attitude while rolling was an unintentional deviation from normal in-flight parameters the risk of which should have been managed by prevention control measures discussed below.

P(a). *The use of suitably experienced pilots.*

The pilot of G-TIMM had not flown high performance, swept wing jet aircraft before converting onto the Gnat and, at the time of the accident, was of Intermediate experience according to CAP 632 criteria. He had flown the aircraft for 11 years, gaining approximately 218 hours on type. A notional RAF Hawk display pilot, having flown a front line fast-jet tour, would have experience of swept wing aircraft and would be classified as Experienced.

P(b). *Suitable currency requirements to maintain handling skills.*

The pilot of G-TIMM flew an average of 12 hours per year during the 5 years before the accident with the majority of the hours being flown on the Gnat. He had flown one display in the previous eight days (and two in the previous nine days, which was close to RAF currency requirements). He had flown four displays in the previous 90 days, which was close to, but in excess of, the CAA minimum of three. He had flown approximately 10 hours and seven displays or practices since 25 April 2015, when his 2015 Gnat flying began[24].

P(c). *A suitable choice of manoeuvres.*

The pilot had flown 'twinkle rolls' many times before and it should not have been a particularly demanding manoeuvre for him to fly. Displaying high performance jet aircraft in a pairs display requires a high degree of coordination but the pilots had displayed together over a number of years.

P(d). *A Safety Management System (SMS) and Quality Management System (QMS).*

SMS and QMS, rather than being barriers in their own right, help to manage the effectiveness of other barriers.

Footnote

24 The pilot flew a Cessna 152 for 1 hour on 31 January 2015 to renew his SEP (land) rating.

The operator's OCM did not have an SMS. The operator did not identify any elevated risk associated with the accident pilot's competence to display the Gnat. Two CAA audits of the operator of the Gnat identified non-conformities with respect to training records but did not highlight any concerns with respect to experience levels, flying training (as opposed to training record-keeping) or recency.

Risk control measures intended to prevent a deviation from normal in-flight parameters from leading to unrecovered loss of control and terrain impact

In circumstances where an unintentional deviation from normal in-flight parameters is not prevented, recovery controls should reduce the risk that the deviation leads to a loss of control, impact with terrain, and casualties on the ground. These recovery control measures are discussed below.

R(a). *The pilot detects and recognises the mishandling.*

The reversal in roll direction suggests that the pilot of G-TIMM recognised the unintended change in nose attitude.

R(b). *The pilot attempts to recover the aircraft in the height available.*

After the nose dropped, the pilot applied an appropriate roll input followed by an inappropriately-timed pitch input, the magnitude of which made a recoverable situation irrecoverable in the height available. Increasing the minimum authorised height increases the margin for error and, with it, the likelihood that an aircraft will be recovered in the height available should control be lost. Increasing the minimum height therefore improves the effectiveness of this risk control measure.

The pilot of G-TIMM was operating to a minimum aerobatic height of 300 ft, although the actual height of the aircraft when the nose attitude dropped was not determined. The benchmark equivalent minimum height used by the RAF is 500 ft.

R(c). *The pilot fails to recover the aircraft and ejects.*

It was not determined whether there was any period after the initial nose attitude change during which the pilot might have ejected safely. The rapid increase in rate of descent, and the banked attitude of the aircraft, would each have reduced the likelihood of a safe ejection from low level. Figures 11 to 13 suggest that the pilot had at least one hand on the control column until very late in the accident sequence, and examination of the wreckage found that the canopy had not been released and the pilot's seat had not moved up its respective mounting tube. It was concluded that the pilot made no attempt to eject.

R(d). *The aircraft impacts terrain clear of the public.*

G-TIMM struck the ground in a wooded area and no other person was injured, although the wreckage straddled a minor public road with the obvious attendant risk of serious adverse consequences. Pilot control inputs observed on the video were highly unlikely to have been made in an attempt to avoid the public.

Figures 1 and 3 show that the display line contained within the display pilots' notes passed through an area marked 'event activity'. The CAA Permission changed the display line but the amended line was not the one used by the display pilots because they were unaware of the change. The day visitor car park and camping site were not included in the information provided to the CAA or display pilots because there was an expectation that they would not be accessible while flying was taking place. The images of G-TIMM provided by the witnesses who were standing in the car park suggests otherwise but it was not determined whether the campsite was also in use. Figure 5 shows that the display line in the CAA Permission passed over the car park and the camping site.

The performance of risk control measures

Prevention controls P(a). and P(b). above (experience and currency requirements) were weaker with respect to the pilot of G-TIMM than they would have been for a notional RAF pilot displaying a similar aircraft. The expense of operating high performance jet aircraft makes it unrealistic for civilian pilots to maintain currency at RAF levels but the pilot of G-TIMM – with an average of 12 flying hours per year over the previous five years – was also using a lower minimum height (300 ft) than the equivalent RAF minimum (500 ft). There is no obvious imperative to reduce the margin for error, or the height available to recover from a mishap, in circumstances where a pilot's experience and currency are relatively low. Therefore:

Safety Recommendation 2016-045

It is recommended that the Civil Aviation Authority amend its policy on minimum aerobatic heights for pilots of high performance jet aircraft such that authorised minima are appropriate to a pilot's experience and currency.

Regarding prevention control P(c). (suitable choice of manoeuvres), the rolling manoeuvres being flown immediately before the accident were relatively simple. However, they were flown at speeds lower than normal and this potentially introduced handling effects which, if not anticipated, might have set up conditions which contributed to the drop in nose attitude during the second roll.

Prevention control P(d). (SMS and QMS) aims to enhance the effectiveness of other controls. It is unlikely, therefore, that an SMS or QMS would identify directly an elevated risk of loss of aircraft control in the context of a pilot who meets all relevant requirements.

Recovery controls R(b). and R(c). above (attempting to recover control and ejecting if necessary) did not prevent impact with the ground and the pilot did not eject. It appeared that the pilot recognised that something was wrong but, faced with a startling, time-critical situation, the timing of his pitch input, and its magnitude, were inappropriate. In circumstances where the time available to act is very short, increased experience and currency are likely to reduce the risk of inappropriate action and improve the likelihood that an aircraft will be recovered safely. In this accident, it is likely that the cumulative effect of a lack of experience on high performance, swept wing jet aircraft prior to flying the Gnat, combined with a low average annual flying rate over the previous five years, contributed to the pilot's inability to recover to wings-level flight.

It is apparent that, in managing the risk of loss of control during display flying, pilot experience and currency are dominant factors influencing the effectiveness of prevention and recovery measures. In this event, these risk controls were not robust enough to prevent the accident and therefore:

Safety Recommendation 2016-046

It is recommended that the Civil Aviation Authority ensure that the experience and currency requirements contained within CAP 403, *Flying Displays and Special Events: A Guide to Safety and Administrative Arrangements,* and CAP 632, *Operation of 'Permit-to-fly' Ex-military Aircraft on the UK Register,* manage the risk of a loss of aircraft control to as low a level as reasonably practicable.

Although G-TIMM struck the ground clear of the crowd, recovery control R(d). (display lines) was weakened: the display line used was not the display line in the CAA Permission; and the display line in the Permission passed over at least one area open to the public. The FDD is responsible to the CAA for the safety of the display but, when the CAA stipulates where the display line should lie, it introduces uncertainty about who is responsible for regulatory compliance and who 'owns' the associated risks. AAIB Special Bulletin S1/2016 discussed the management of risk at flying displays and recommended that the CAA introduce a process whereby organisers of flying displays conduct appropriate risk assessments before a Permission is granted under Article 162 of the ANO.

Medical factors

The evidence available was that the pilot had not experienced any symptoms of his medical condition in the recent past and that, when he had experienced symptoms before 2001, they had been mild. Had the pilot experienced any appreciable symptoms immediately before the final manoeuvre, it is likely that he would have curtailed his display. The manoeuvre that the aircraft was flying was not a high-g manoeuvre, which the CAA stated can bring on symptoms, although the large pitch input would have led to a high-g situation. However, it was the pitch input which made the situation irrecoverable and any subsequent G-LOC would have been consequential rather than causal. The pitch input required the pilot to have made an aft input on the control column. The right-roll input was present until the aircraft was at tree-top height and the situation was beyond recovery.

Had the control column been released at any stage due to incapacitation, the ailerons and tailplane would have returned to their neutral positions and this was not observed. It was concluded that the pilot was consciously at the controls until immediately before impact and not incapacitated.

Notwithstanding this conclusion, according to the CAA the pilot's medical condition was unlikely to have been detected, given that it was not declared and the requirements of Class 2 medicals do not include routine ECGs before age 40. Routine ECGs, and/or more rigorous medical examinations might have identified this condition and might also help identify other medical conditions the symptoms of which could be detrimental to displaying high performance aircraft. Therefore:

Safety Recommendation 2016-047

It is recommended that the Civil Aviation Authority review the medical examination requirements for pilots displaying high performance aircraft to improve the likelihood that medical conditions are identified which are potentially detrimental to displaying such aircraft safely.

Conclusion

Examination of the aircraft revealed no evidence of a pre-existing problem that could have led to the accident. Examination of video evidence indicated that the flying controls were probably functioning normally. The aircraft was carrying out an aileron roll at low level when, at an angle of bank of 107° to the left, the nose attitude dropped relative to the horizon. The pilot applied an appropriate roll input, probably in an attempt to recover, but then applied an inappropriately-timed pitch input. The pitch input led to a high rate of descent, caused the aircraft to depart from controlled flight and made the situation irrecoverable in the height available. The pilot's experience and currency were considered to be contributory factors.