AAIB

Air Accidents Investigation Branch

AAIB Bulletin 2/2020

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(ALL TIMES IN THIS BULLETIN ARE UTC)

AAIB Field Investigation Reports

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

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

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

SERIOUS INCIDENT

Aircraft Type and Registration:	Airbus A320-214, G-EZTD
No & Type of Engines:	2 CFM56-5B4/3 turbofan engines
Year of Manufacture:	2009 (Serial no: 3909)
Date & Time (UTC):	24 April 2019 at 2022 hrs
Location:	Lisbon Airport, Portugal
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 6 Passengers - 175
Injuries:	Crew - None Passengers - None
Nature of Damage:	None reported
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	27 years
Commander's Flying Experience:	4,300 hours (of which 4,100 were on type) Last 90 days - 162 hours Last 28 days - 38 hours
Information Source:	AAIB Field Investigation

Synopsis

Under international protocols, this investigation was delegated to the AAIB by the Gabinete de Prevenção e Investigação de Acidentes com Aeronaves e de Acidentes Ferroviários (GPIAAF) in Portugal.

During pre-flight preparations, both pilots completed a takeoff performance calculation for a takeoff from the runway intersection with Taxiway U5. During subsequent re-planning, the crew thought they had recalculated performance information from Taxiway S1 but had, in fact, used S4 (runway full length). The aircraft took off from Taxiway U5 with performance calculated for the full runway length. The takeoff distance available from U5 was 1,395 m less than that used for the performance calculation, and the aircraft passed the upwind end of the runway at 100 ft aal. The operator had another identical event 14 days later.

Following this event, the operator acted to raise awareness of the issue with its crews and engaged with the aircraft manufacturer to review possible technical developments which might prevent a recurrence of these type of events.

One Safety Recommendation is made to mitigate the risk of further confusion relating to takeoff positions.

History of the flight

The aircraft was making the return flight to London Luton Airport from Lisbon Airport having arrived at Lisbon at 1940 hrs. The crew initially planned for a departure from the intersection of Taxiway U5 with Runway 21 (Figure 1) and both pilots completed the performance calculations from this intersection (Takeoff Run Available (TORA) 2,410 m). This intersection was referred to as '*PSNUTMP'* (temporary position U)[1] in the Electronic Flight Bag (EFB). The crew subsequently re-planned for a departure from Taxiway S1, but in recalculating the performance they both selected '*PSNSTMP' (*temporary position S). This position was the intersection of Taxiway S4 with the runway ie the full length of the runway. The crew did not cross check the TORA from PSNSTMP against the TORA from Taxiway S1, so the error was not identified by the crew before takeoff.

The aircraft departed from the Taxiway U5 intersection (TORA 2,410 m) at 2034 hrs using an engine thrust setting based on performance figures calculated for the full length of the runway (TORA 3,805 m) (Figure 2). With the reduced power setting, the commander commented subsequently that the takeoff "felt wrong", but Takeoff/Go-around (TOGA) thrust was not selected. The aircraft passed the upwind threshold of the runway at a height of approximately 100 ft. During the flight, the crew realised what had happened and reported it to the operator after landing.

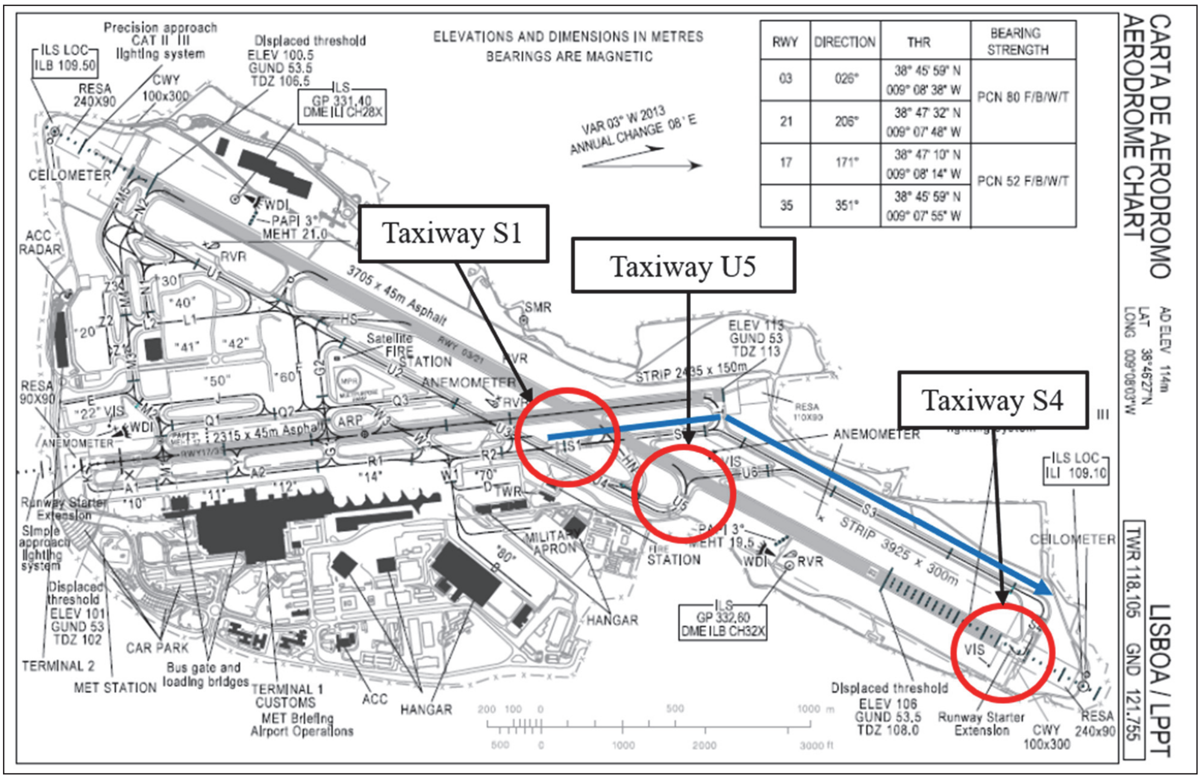

Figure 1

Plan of Lisbon airport showing Taxiways S1, U5 and S4
(chart not orientated north-up)

Footnote

1 See later sections, *Airfield information* and *Electronic flight bag nomenclature.*

Figure 2

Image of Lisbon Airport showing the calculated and actual takeoff points

Recorded information

Data from the FDR and digital access recorder (DAR) were downloaded from the aircraft by the operator on arrival at Luton and copies were subsequently provided to the AAIB. The DAR is used to provide data for the operator's Flight Data Monitoring (FDM) programme. The 2-hour duration CVR recording was sent to the AAIB for download and analysis, but the duration of the flight from Lisbon meant that the takeoff portion of the flight had been overwritten by the time the aircraft landed.

Analysis of the FDR data for the event showed that the takeoff roll was about 1,860 m long, with the aircraft becoming airborne 400 m before the upwind runway threshold, which it overflew at 100 ft climbing at about 2,700 ft/min. The airspeed at lift off was 170 KIAS.

Airfield information

Lisbon Airport has two runways which are orientated 03/21 and 17/35 as shown in Figures 1 and 3. Runway 03/21 is the preferred runway for both takeoffs and landings, and the prevailing winds mean that Runway 03 is more commonly used. At the time of publication, Runway 17/35 was expected to close and become a taxiway.

For reasons described as "historic", runway takeoff points are referred to as '*Positions*' in the Aeronautical Information Publication[2] (AIP) entry for Lisbon Airport. It is typical for airports elsewhere to use the intersection of taxiways with a runway to describe takeoff points. Commercial chart companies use information from the AIP to generate their publications and takeoff performance data, and they therefore refer to Positions at Lisbon Airport. However, Positions are not generally used by Lisbon ATC when issuing clearances.

When Runway 21 is in use, the preferred takeoff point for all aircraft except heavy jets is 'Position U', which is the intersection of the runway with Taxiway U5. Pilots must advise ATC

Footnote

2 Aeronautical Information Publication (AIP) is a publication issued by or with the authority of a State and containing aeronautical information of a lasting character essential to air navigation. (ICAO Annex 15 - Aeronautical Information Services.)

on start-up if they require the full length of the runway for takeoff. Full-length departures are from Holding Point S4, which is known as 'Position S'. Taxiway S begins abeam Runway 17, before crossing Runway 21 at Taxiway S1, and then turning north-east to run parallel to Runway 21 (marked on Figure 1 in blue). The taxiway ends at the threshold of Runway 21. There are therefore two points on Runway 21 where Taxiway S intersects the runway.

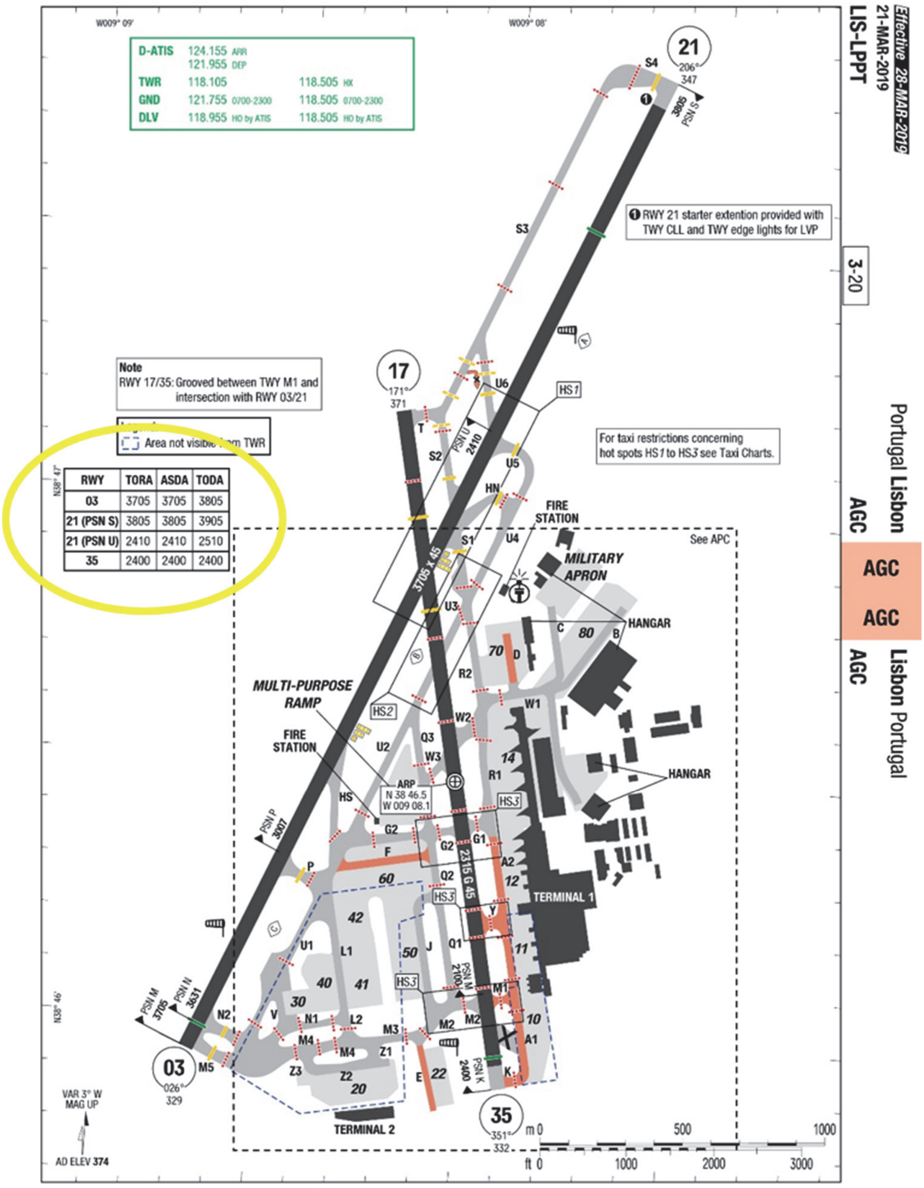

Figure 3

Lisbon aerodrome ground chart © LIDO

Operational procedures

The operator uses an EFB to calculate the weight and balance of the aircraft as well as takeoff performance. Both pilots have a tablet computer on which they complete the required calculations.

Electronic flight bag nomenclature

Data for the EFB performance software is supplied to the operator by a third party. Within the software the crew must initially select the runway for departure and then a point on that runway from where the takeoff will begin. Some runways may have multiple intersections available for departure and, in the case of Lisbon Runway 21, two positions are available, Position U and Position S. These are named in the software as PSNU and PSNS.

At the time of the incident, there was a NOTAM affecting the takeoff performance calculation (referring to an obstacle in the climb-out zone). This meant that the data supplier had inserted two further temporary selections for the two takeoff positions for Runway 21, which were labelled PSNUTMP and PSNSTMP as shown in Figure 4.

Figure 4

EFB dropdown menu showing the all the intersections available

The crew initially selected PSNUTMP for the performance calculation, ie intersection U5, but in discussing the likely takeoff point, they decided that they could use the S1 intersection if necessary, from which there was a lower TORA than from U5. They then performed the calculation from what they thought was the S1 intersection in the EFB selection: PSNSTMP.

Operator's procedures

The operator has detailed standard operating procedures (SOPs) for calculating performance information for takeoff, and each pilot must make the calculation independently before push back. Before completing the performance calculation, the pilots must agree which intersection they will use for the calculation, using the one most likely to be used for takeoff. Should the aircraft depart from a less limiting intersection, no further performance calculation is required. The length of the runway selected is shown on the EFB calculation as shown in Figure 5.

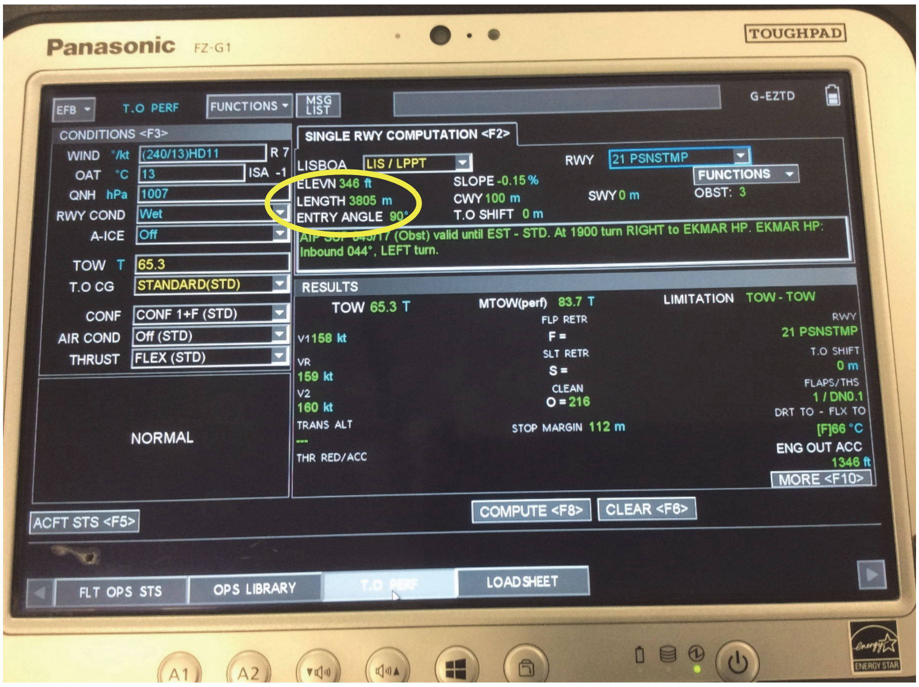

Figure 5

Performance calculation from the temporary Position S showing the distance display

Both pilots are required to cross-check the runway distances available from the chosen intersection against the lengths displayed on the aerodrome ground chart, as shown circled in yellow in Figure 3 for Lisbon.

Further event

The operator subsequently reported an identical event which occurred with another company aircraft 14 days later. This event involved A320-214, registration OE-IJL, which departed Lisbon at 1906 hrs on 7 May 2019 for a flight to Paris Charles de Gaulle Airport. In this event, the aircraft lifted off 350 m before the upwind runway threshold which it crossed at about 75 ft aal.

Further information

The AAIB has investigated numerous serious incidents where aircraft have taken off using performance information calculated from a different start point. Worldwide, similar events present a significant hazard to civil aviation despite SOPs containing measures designed to prevent them, such as cross-checks and independent calculations. Pilots performing cross-checks often fail to notice errors or differences when the figures are unexpected. Humans are poorly adapted physiologically to discriminate between slightly-different acceleration rates, and many years of training have made pilots reluctant to move the throttles once takeoff power is set[3]. In recognition of this, the AAIB has previously

Footnote

3 AAIB report into a serious incident in Belfast Aldergrove Airport, Boeing 737, C-FWGH, took off with insufficient thrust for the environmental conditions and struck an obstacle after lift-off https://www.gov.uk/aaib-reports/aircraft-accident-report-aar-2-2018-c-fwgh-21july-2017 [accessed December 2019]

recommended that a technical barrier should be developed to capture the effects of an incorrect takeoff performance calculation when it occurs.

The CAA has been working closely with EASA, operators, manufacturers and the AAIB to drive forward developments in mitigation strategies for takeoff performance errors. The strategies include increasing awareness in crews and operators about the criticality of takeoff performance data, development of flight data monitoring flags to detect takeoff performance errors, and the possibility of technological barriers to trap the effects of errors that are made. A copy of a letter on takeoff performance safety sent by the CAA to the CAT industry in December 2018 is at Appendix A.

The aircraft manufacturer has developed a system aimed at protecting against incorrectly-calculated takeoff performance information for other types of aircraft within its fleet. This system performs a lift-off distance check and an aircraft position check before the aircraft begins its takeoff roll, and the manufacturer is in the process of extending the availability of this system to the A320 series of aircraft. The aircraft manufacturer indicated that the trial system would not have warned the crews of G-EZTD or OE-IJL against taking off because, at the start of the takeoff roll, the system-calculated value for runway remaining exceeded the forecast lift-off distance.

Analysis

During pre-flight preparation, both flight crew selected PSNSTMP in the EFB as the reference point for the takeoff performance calculation believing it to be where Taxiway S1 crossed Runway 21 whereas it was actually the reference point for the full length of the runway. The use of takeoff Positions gave rise to the situation where two points on Runway 21 could be construed by the crew as being ‘Position S’ within the EFB performance software.

The operator’s SOPs required the crew to crosscheck the takeoff distance shown in the EFB against the equivalent distance shown on the aerodrome ground chart, but this crosscheck did not capture the error. Consequently, a lower thrust setting than required was used for the takeoff from S1 because it had been calculated for the full length of the runway (which had an additional 1,395 m available). After lifting off, the aircraft passed the upwind end of the runway at 100 ft aal.

Another aircraft from the same operator, although operating under a different AOC, had an identical serious incident 14 days later. In both cases the pilots were confused by the EFB intersection selections because they did not refer to taxiway names, and the selection PSNSTMP could be confused between two runway intersections, S1 or S4. Therefore, the following Safety Recommendation is made:

Safety Recommendation 2020-003

It is recommended that ANA Aeroportos de Portugal discontinue the use of takeoff ‘Positions’ at Lisbon Airport to minimise confusion in relation to takeoff points.

Conclusion

Both aircraft took off using incorrect performance data for the intersection used. In each case, a selection error was made in the EFB which led the crew to believe that they had calculated performance information for a departure from S1 when in fact they had selected the full length of the runway. In both cases, the procedural barrier of cross-checking the runway distance against the aerodrome ground chart failed to prevent to error. Human performance limitations mean it is difficult for pilots to recognise and react to reduced performance (acceleration) once the takeoff has begun, so robust adherence to procedures is a key defence against such incidents occurring.

Safety action

As a result of these serious incidents the following safety action was taken:

- The aircraft operator issued a notice to its flight crew clarifying the takeoff positions available on Runway 21 at Lisbon Airport.
- A NOTAM was issued highlighting '*confusing runway holding point naming'* and reminding crews that 'Position S' referred to the full length of Runway 21 (Figure 6).
- The aircraft operator issued a description of the events and their causes to its flight crew to raise awareness of the risks of using the wrong intersection and distance for takeoff.
- The aircraft operator engaged with the aircraft manufacturer to review future developments that could offer extra protections against events such as those covered in this report.
- The airport authority undertook to rename taxiways so that Taxiway S intersected the runway at only one point; S4 (full length).

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LPPT/LIS RUNWAY EXCURSION
08/05/2019 - UFN

LPPT/LIS

TEMP NOTE - RUNWAY EXCURSION

CONFUSING RUNWAY HOLDING POINT NAMING AND CREW ARE REMINDED TO
CHECK THE RUNWAY LENGTH DISPLAYED ON THE EFB WITH THE AGC. RUNWAY
21 POSN S REFERS TO THE FULL LENGTH RUNWAY.

BACKGROUND INFORMATION:
REPORTS HAVE BEEN RECEIVED WHERE CREW HAVE ASSUMED EFB PERFORMANCE
FOR PSN S REFERS TO TAXIWAY INTERSECTION S1 OF RUNWAY 21. THERE ARE
NO PERFORMANCE FIGURES AVAILABLE FOR INTERSECTION S1. CREW CAN
EXPECT TO DEPART FROM INTERSECTION U.
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Figure 6
Crew NOTAM

Appendix A

Letter from the CAA to the Commercial Air Transport industry

Chief Executive's Office

Civil Aviation Authority

10 December 2018

Incidents and errors affecting take-off performance safety: a global aviation issue

Sector: large commercial air transport aeroplane (CAT)

The UK Civil Aviation Authority (CAA) has been monitoring domestic and foreign take-off performance incidents and accidents very closely for some time. Whilst we have engaged with our industry to raise awareness of this risk, the CAA Board has determined that more needs to be done, especially in the area of devising technological barriers that will prevent further occurrences.

Significant incidents continue to occur globally and, in some cases, investigations have revealed that all safety margins were eroded. It is a widely held belief that not all incidents are reported and flight data monitoring programmes are, in many cases, not covering this area. Some recent examples relevant to take-off performance error include:

- Boeing 777 at London Heathrow – Full runway length data used for initial calculation, but flight crew accepted an intersection departure. The First officer recognised the different, but changed data to match the Captain's full-length date with no cross-check (Indian AAIB report issued Aug 2018)
- Boeing 737 at Belfast – Incorrect data entered in the assumed temperature field resulting in the take-off thrust being less than was required (UK AAIB Special Bulletin 20 Sep 2017)
- Airbus A320 at Luton – Intersection departure with full length data used. Crew were distracted by ensuring the different flap setting that was required was selected, but missed the runway length discrepancy (UK AAIB report published 14 Jan 2016)
- Airbus A320 at Malaga – incorrect runway data used for departure and the crew only noticed when they cross-checked calculations in the cruise (UK AAIB report published 12 Jan 2017)
- Airbus A320 at Belfast – System anomaly defaulted to wrong runway after change to input data and was not spotted by crew (UK AAIB investigation published 12 May 2016)

And:

- On Friday 12 October, an Air India Express B737-800 hit a low wall at the departure end of the runway in use. The images are quite alarming and it does not take an aviation expert to conclude that this could so easily have resulted in a much worse outcome. Whilst we must all respect the integrity of the investigation process, this incident must be a catalyst for more activity to be undertaken by all parties, including manufacturer (OEM), operator and regulator.

Whilst much of the focus to date has been on Human Factors and procedure design, which remain key areas for continued improvement, the UK CAA very much supports the development and implementation of technology-based solutions which could provide vital additional controls to the barriers currently in use and development.

Civil Aviation Authority
K5, CAA House, 45-59 Kingsway, London, WC2B 6TE www.caa.co.uk
Telephone 020 7453 6003

The UK CAA has been working closely with the European Aviation Safety Agency following the Agency's 2016 bulletin[1] and its associated 2018 survey on wrong take-off parameters, to develop appropriate mitigations. The UK CAA will continue to work with EASA in order to further elaborate on relevant actions as part of the European Plan for Aviation Safety (EPAS). In parallel to this work and given the four UK specific incidents above, the UK and its AAIB have established a working group to look in more depth at this issue. This has highlighted the following actions:

- Crew awareness – it is apparent that many crews don't understand the criticality of take-off performance data and the errors and traps with data processing and data entry. This is especially important as analysis has demonstrated that the only significant barriers in the chain are human-based, i.e. process and procedure.

- Operator awareness – Until recently, very few operators have been looking for take-off errors in their FDM programmes and safety reporting systems have not flagged up many issues as, unless the error is significant, crews rarely report an issue after the event. Experience has shown that operators that have had issues and educate crews then see an increase in safety reports about take-off performance errors.

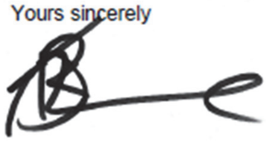
- Technological barriers – All the current barriers are human-based and what is required is a technological barrier, as late in the take-off process as possible to trap as many errors as possible. A recent EUROCAE project around take-off performance declared that a 100% effective take-off performance tool was unachievable. The group is, however, supporting a simple system that would trap gross errors by detecting insufficient acceleration during the take-off roll and alerting the crew during the 'slow speed' phase of the take-off to allow a safe stop to be made. A system is currently available on Airbus A380 aircraft and an Avionics manufacturer has trialled a simple retrofit solution based on EGPWS.

The UK CAA plans to keep the Take-Off Performance working group running for as long as necessary and in the meantime, will endeavour to increase crew and operator awareness. At the same time, the position of the UK CAA Board is to strongly encourage OEMs to develop and support a take-off performance alerting system and note that certain technology already exists.

The UK CAA would be encouraged by all stakeholders recognising the importance of this issue and agreeing to do more to prevent further incidents. We would like to understand your perspective on this issue and would welcome the establishment of a global task force to help develop proposals aimed at addressing this risk. If it is established by commercial industry, the UK CAA would be willing to join such a global take force, in order that we determine the next steps.

We look forward to receiving your response.

Yours sincerely



Richard Moriarty
CHIEF EXECUTIVE

[1] EASA SIB 2016-02

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Telephone 020 7453 6003

Published: 16 January 2020.

SERIOUS INCIDENT

Aircraft Type and Registration:	1) EMB-145EP, G-SAJK 2) Cessna P210N Pressurized Centurion, G-CDMH
No & Type of Engines:	1) 2 Allison AE 3007/A1/1 turbofan engines 2) 1 Continental Motors TSIO-520-P piston engine
Year of Manufacture:	1) 1999 (Serial no: 145153) 2) 1978 (Serial no: P210-00131)
Date & Time (UTC):	7 August 2019 at 1740 hrs
Location:	London Southend Airport
Type of Flight:	1) Commercial Air Transport (Passenger) 2) Private
Persons on Board:	1) Crew - 3 Passengers - 35 2) Crew - 1 Passengers - None
Injuries:	1) Crew - None Passengers - None 2) Crew - None Passengers - N/A
Nature of Damage:	1) None reported 2) None reported
Commander's Licence:	1) Airline Transport Pilot's Licence 2) Private Pilot's Licence
Commander's Age:	1) 39 years 2) 51 years
Commander's Flying Experience:	1) 7,453 hours (of which 1,075 were on type) Last 90 days - 110 hours Last 28 days - 74 hours 2) 1,930 hours (of which 169 were on type) Last 90 days - 23 hours Last 28 days - 10 hours
Information Source:	AAIB Field Investigation

Synopsis

An Embraer 145 landing at London Southend Airport ran over a general aviation towbar which had been dropped on the runway. No damage was caused to the aircraft. The investigation found that the towbar had fallen from a Cessna 210 which departed Southend Airport 30 minutes before. The Cessna pilot had likely been distracted during his pre-flight checks by an earlier road traffic incident in which he was involved, and had inadvertently left the towbar attached.

One Safety Recommendation has been made to the CAA to improve the visibility of general aviation ground equipment.

History of the flight

G-SAJK – Embraer 145

G-SAJK was operating a scheduled service from Aberdeen to Southend, and made a normal approach to Runway 23 at Southend Airport, landing at 1815 hrs. The weather conditions were CAVOK. On landing, as the commander applied the brakes, he saw an object on the right of the centreline approximately 8 – 10 m in front of the aircraft. He estimated that the aircraft was travelling at between 105 and 110 kt at this stage. He applied slight left rudder as the object disappeared out of view and felt a small bump through the rudder pedals but was not sure if this was caused by the aircraft clipping the object or running over the centreline. The aircraft stopped, backtracked and vacated the runway normally.

The commander reported the sighting to ATC who requested a runway inspection, which found a general aviation towbar (Figure 1) on the runway. There were no indications of any damage to the aircraft, so the commander continued to taxi the aircraft to stand. After the passengers had disembarked, both pilots inspected the aircraft but found no damage.

The commander recalled that the object had been very difficult to see against the dark asphalt runway. He only saw it because part of the towbar was lying across the white centreline markings. He recalled that it was located just after Taxiway B.

Shortly after the Embraer landed, Southend ATC received a call from Farnborough Radar. They had been notified by the pilot of a Cessna P210 (G-CDMH), which had departed Southend Airport at 1747 hrs, that he thought he may have departed with the towbar still attached.

G-CDMH - Cessna 210

The pilot flew to Southend Airport regularly as he had an office nearby. He travelled between his office and the airport by motorcycle. On the day of the incident, whilst riding to the airport, a cyclist pulled out in front of him. He was able to miss the cyclist, and no one was injured, but the pilot described it as “a fright and a close shave.” He continued to the airport, pulled the aircraft out of the hangar and completed the pre-flight checks. The start-up was uneventful but, as he taxied to the runway, he noticed a slight tendency for the aircraft to track to the left. However, he considered it minor and made a mental note to check the tyre pressures on landing. The pilot reported that the takeoff from Runway 23 seemed entirely uneventful.

Approximately 30 minutes into the flight he was thinking about the tracking issue and it occurred to him that he could not positively remember removing and stowing the towbar. He knew the towbar was no longer attached to the aircraft because the landing gear had successfully retracted. He immediately reported his concern to Farnborough Radar and asked for a message to be passed to Southend. The pilot continued his planned flight and landed without further incident. He inspected the aircraft after landing and did not find any damage.

The pilot discovered that he had also left his bags behind in the hangar at Southend. He reflected that he was distracted by the earlier motorcycle incident and that this was "on his mind" whilst completing the pre-flight checks. He reported that "the towbar is a small stowable unit that does not extend outwards much more than the tip of the spinner, but it is quite obvious and I cannot believe that I missed it."

ATC report

After the landing Embraer reported seeing the towbar, ATC asked an operations vehicle to inspect the runway. They recovered the towbar from the runway approximately 50 m to the west of Taxiway B (Figure 1). There were scuff marks on the handle of the towbar. Between G-CDMH departing and G-SAJK landing two other aircraft had used the runway and a runway inspection had been carried out. Table 1 gives a summary of the timeline provided by ATC.

TIME	EVENT
1739	G-CDMH has cleared to taxi to holding point D where the aircraft carried out power checks.
1743	G-CDMH reported ready for departure.
1746	G-CDMH was cleared for takeoff and was recorded as airborne at 1747 hrs. G-CDMH was subsequently handed-over to Southend Radar.
1749	A PA-28 on a local flight was cleared to land on Runway 23.
1752	The PA-28 landed.
1753	An Operations vehicle was cleared to enter the Runway at C1 to complete an inspection. The vehicle entered the Runway initially in a south-westerly direction and on return vacated at Taxiway D at 1757 hrs.
1759	A Britten-Norman Islander was cleared to taxi to A1 and was then cleared to takeoff at 1801 hrs. The aircraft was recorded as airborne at 1803 hrs.
1811	G-SAJK was cleared to land.
1815	G-SAJK landed and the commander reported the aircraft had colliding with a general aviation towbar on the runway.
1817	An operations vehicle recovered the towbar adjacent to Taxiway B.
1825	ATC received a call from Farnborough Radar reporting the G-CDMH may not have removed their towbar prior to departure.

Table 1

Summary of the timeline of the incident

ATC reported that it was not possible to see the towbar from the control tower due to its size, shape and colour. They also reported that at the time of the event the location of the evening sun made it harder to see objects on the runway.

Figure 1
Towbar recovered from the runway

Runway inspection report

At 1751 hrs a fire officer driving an airport operations vehicle requested permission to enter the runway for a wildlife inspection. Permission was granted at 1753 hrs. He entered the runway at C1 and preceded south-west toward the Runway 05 threshold. He reported that when he entered the runway there was no wildlife activity, so he carried out a surface inspection. From the Runway 05 threshold he recalled that he drove to the Runway 23 threshold then back to Taxiway D where he vacated. He did not see the towbar. He vacated the runway at 1757 hrs.

It was reported that because his initial intention was to complete a wildlife inspection his attention may have been directed towards the sky rather than on the surface which may be why he did not see the towbar.

Airfield information

London Southend Airport has a single asphalt runway orientated 05/23 (Figure 2).

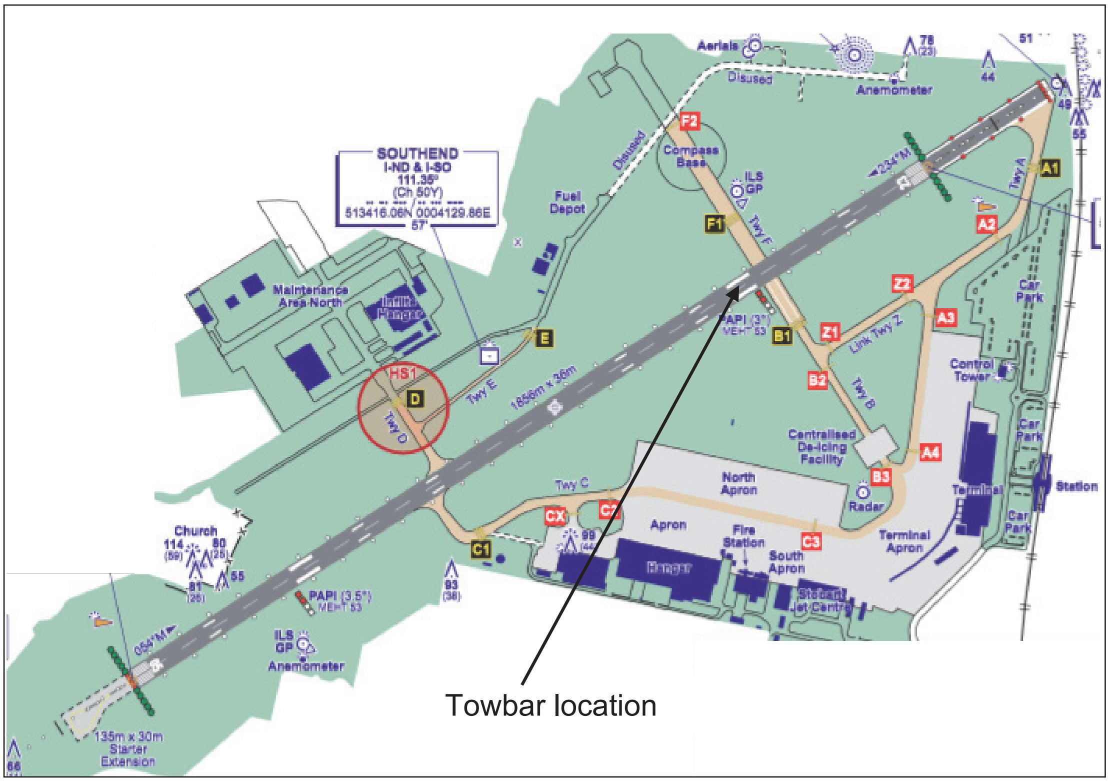

Figure 2

London Southend Airport Chart showing approximate location the towbar was found.

The airport does not have any electronic means of detecting objects on the runway, taxiways or apron[1] so relies on them being seen during runway inspections or being reported by other airfield users.

London Southend Airport procedures specify a minimum of one runway inspection every four hours and two complete movement area inspections daily. On the day of the incident, airport records show that the last full runway inspection was completed at 1515 hrs. The inspection which occurred between the Cessna departing and the Embraer landing was intended to be a wildlife inspection and not considered a full runway inspection.

Personnel

The pilot of the Cessna 210 (G-CDMH) held a Private Pilot's Licence with valid Single Engine Piston, Multi Engine Piston and Instrument (IR) ratings. He had a total of 1,930 flying hours with 169 hours on the Cessna 210. He had flown 10 hours in the last 28 days and 23 hours in the last 90 days.

Footnote

1 Some larger airports have 'foreign object detection radar' which can detect objects on the runway and issue alerts to ATC.

All times are UTC

Pre-flight checklist

During the airport's investigation into this incident it was noted that the pre-flight checklist used by the pilot did not include any reference to ensuring the towbar, or other ground equipment, is removed before flight.

Following the incident, the pilot amended his checklist to add a reminder to remove and stow the towbar. Additionally, he added a visual reminder in the cockpit of G-CDMH.

Other human factors

The pilot was involved in a motorcycle incident during his drive to the airport. He reported that this incident was "on his mind" during his pre-flight checks and probably contributed to him forgetting to remove the towbar. Additionally, he left two of his bags behind at the airport which also suggests he was distracted.

A stressful or traumatic event can be distracting and difficult to put out of mind. It may be tempting to continue with a planned operation and not realise the effect of such an event on subsequent performance.

The CAA Skyway Code[2] highlights the importance of pilots assessing their fitness to fly before any flight. The code suggests using the 'IM SAFE' mnemonic for self-assessing fitness for flight (Figure 3). In this incident 'stress' from the earlier motorcycle incident was probably a key factor.

> **Illness** – are you suffering from any?
> **Medication** – are you taking any?
> **Stress** – are you suffering from any?
> **Alcohol** – when did you last drink?
> **Fatigue** – are you well rested?
> **Eating** – have you eaten recently?

Figure 3

'IM SAFE' mnemonic highlighted in the CAA Skyway Code

Ground equipment markings

The towbar was painted in a dark blue paint (Figure 1) which made it difficult to see against the dark asphalt runway surface.

Footnote

[2] CAA skyway Code is available at https://www.caa.co.uk/General-aviation/Safety-information/The-Skyway-Code (accessed 16 October 2019)

The International Air Transport Association (IATA) Airport Handling Manual (AHM)[3] provides recommendations for aircraft ground support equipment. AMH 913 section 14 lists the following recommendations for non-motorised ground support equipment:

'14.2.1 Non-motorised Ground Support Equipment should be visible to the operator(s) of any approaching Ground Support Equipment within the safety braking distance and under any angle of approach.

14.2.2 Colour schemes for markings of reflective material should be in compliance with the marking and illumination standards established by the local regulatory authorities. The reflective material shall be resistant to wear and tear.

14.2.3 Non-motorised Ground Support Equipment should have its presence accentuated by application of reflective material on all sides of the equipment inclusive of the tow-bar, outriggers or any other deployable devices.

14.2.4 Non-motorised Ground Support Equipment should have a minimum of 2 markings of reflective material on each side of the equipment with a maximum separation distance of 1.5 m (60 in) between each marking. Each marking should not be less than 100 cm² (15.49 in²).

14.2.5 Markings of reflective material should also be applied on all comers of the equipment.'

Analysis

The pilot of a Cessna 210 departing from Southend Airport inadvertently left the aircraft's towbar attached to the nosewheel. As the aircraft took off the towbar fell off and landed on the runway. The towbar remained on the runway for approximately 30 minutes during which time another aircraft landed, another took off and an operations vehicle completed an inspection. A landing Embraer 145 ran over the towbar during its landing roll.

The pilot of the Cessna reported that he was distracted by an early road traffic incident and this is probably why he forgot to remove the towbar. The incident highlights how stress from events unrelated to flying can cause a significant distraction and the importance of pilots honestly assessing their fitness for flight prior to every flight.

The towbar was not seen on the runway by two other aircraft that used the runway nor by a fire officer conducting an inspection. It is not known exactly which part of the runway the two aircraft used, so it is possible they did not pass the towbar. Alternatively, their attention may have been on flying their aircraft. The inspection was initially intended to be a wildlife inspection, so it is possible that the driver's attention was focused towards the sky rather than the runway surface. However, the towbar was painted in dark colours so it did not stand out against the runway surface. The towbar might have been seen sooner if it had reflective or other high visibility markings.

Footnote

3 IATA Airport Handling Manual is available at https://www.iata.org/publications/store/Pages/airport-handling-manual.aspx (accessed 16 October 2019)

Most airports do not currently have automatic means of detecting objects on the manoeuvring area, so they rely on them being seen during inspections or being seen by other airport users. Therefore, it is important that any equipment that could be left on a manoeuvring area is highly visible.

The IATA AHM provides recommendations for ground handling equipment to ensure it is clearly visible. However, these are not widely applied across general aviation ground equipment. Making ground equipment more visible would reduce the likelihood of it being left attached to the aircraft and increase the chance of it being seen quickly if it is left on a runway or manoeuvring area.

During this incident no damage was caused to the landing aircraft. However, objects on the manoeuvring area have the potential to cause serious harm to aircraft.

Therefore, the following Safety Recommendation is made:

Safety Recommendation 2020-004

It is recommended that the Civil Aviation Authority communicate to the general aviation community the importance of increasing the visibility of ground equipment.

Conclusion

A general aviation towbar was inadvertently left attached to an aircraft because the pilot had been distracted by an earlier stressful event during his journey to the airport. The towbar dropped onto the runway during the departure and remained there for approximately 30 minutes, during which two other aircraft used the runway and a runway inspection was completed. A landing aircraft then ran over it. The towbar was inconspicuous because it did not have any reflective or other high visibility markings.

Safety action

The CAA has stated that if, during the general aviation-specific audits and inspections it conducts, it observes ground equipment that due to its colour is not sufficiently visible, it will bring this to the attention of the relevant operator.

Published: 23 January 2020.

AAIB Correspondence Reports

These are reports on accidents and incidents which were not subject to a Field Investigation.

They are wholly, or largely, based on information provided by the aircraft commander in an Aircraft Accident Report Form (AARF) and in some cases additional information from other sources.

The accuracy of the information provided cannot be assured.

SERIOUS INCIDENT

Aircraft Type and Registration:	Airbus A320, EI-DEO
No & Type of Engines:	2 CFMI CFM56-5B4/PS turbofan engines
Year of Manufacture:	2005
Date & Time (UTC):	12 August 2019 at 2100 hrs
Location:	En route from Dublin Airport to London Heathrow Airport
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 6 Passengers - 173
Injuries:	Crew - None Passengers - None
Nature of Damage:	None
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	42 years
Commander's Flying Experience:	8,000 hours (of which 5,000 were on type) Last 90 days - 16 hours Last 28 days - 6 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

After completing a cross-bleed start[1], both flight crewmembers experienced a strong fuel/oil smell which they assumed was as a result of the start procedure. During taxi, they experienced further fuel/oil fumes and thought it was due to the exhaust of an aircraft taxiing ahead. Further intermittent occurrences of fumes were noticed during departure and climb which they discussed.

Whilst the flight crew were conducting their approach brief, they discussed that they both felt they were not operating to their normal standard and agreed they would maintain a heightened awareness. They did not think it necessary to don oxygen masks. The approach and landing were without incident. After landing the flight crew opened the cockpit direct vision windows and taxied onto stand. During a post flight review, unsure of their medical condition, both flight crew donned the oxygen masks for a short while. A basic medical examination of the flight crew showed that all their vital signs were normal.

The aircraft was subjected to extensive fault finding by engineering staff, no cause for the fumes was identified and the aircraft has returned to operation with no further reports of fumes.

Footnote

[1] The aircraft was operating with its APU inoperative. As a result, the first engine had to be started on stand using a ground air supply. The second engine was then started after push-back using bleed air from the first engine using a cross-bleed procedure.

The operator completed an internal investigation and is reviewing smoke and fumes guidance material provided to its flight crew.

ACCIDENT

Aircraft Type and Registration:	Airbus A340-642, G-VFIT
No & Type of Engines:	4 Rolls-Royce RB211 Trent 556-61 turbofan engines
Year of Manufacture:	2006 (Serial no: 753)
Date & Time (UTC):	21 August 2019 at 1230 hrs
Location:	En route from New Delhi Airport, India to London Heathrow Airport
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 15 Passengers - 305
Injuries:	Crew - 1 (Minor) Passengers - 1 (Serious)
Nature of Damage:	None
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	54 years
Commander's Flying Experience:	18,062 hours (of which 5,722 were on type) Last 90 days - 162 hours Last 28 days - 62 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot and further enquires by the AAIB

Synopsis

Whilst passing through northern Turkey at FL360 the aircraft encountered moderate to severe turbulence during which a passenger was severely injured. The turbulence was not forecast and there were no indications, visually or on the aircraft's weather radar, to suggest the aircraft was approaching an area of turbulence.

History of the flight

G-VFIT, an Airbus A340, was flying from New Delhi Airport, India to London Heathrow Airport (Heathrow). At approximately 1230 hrs, five and a half hours into the flight, the aircraft was over northern Turkey, at FL360, routing toward the border with Bulgaria (Figure 1). The commander had just returned from his rest period. The relief co-pilot was in the right seat and was the pilot flying. The weather forecast for the area was for isolated embedded cumulonimbus clouds with tops at FL320.

The commander reported that as they approached waypoint OLUPO (Figure 1) he saw a single "non-threatening" cloud on their track which was not showing on the aircraft's weather radar. There were cumulonimbus clouds on the horizon but no other clouds in their immediate vicinity. The aircraft was then cleared from OLUPO direct to waypoint ODERO on the Turkey/Bulgaria border, which took the aircraft clear of the single cloud. However, as the aircraft passed abeam the cloud, they encountered moderate to severe turbulence. The co-pilot saw the speed trend arrow indicating +40 kt and the speed increasing rapidly. To prevent an overspeed he selected a lower Mach number and extended the speed brakes. The commander turned the seatbelt signs ON. The commander recalled seeing the wind shifting from a 40 kt tailwind to a 20 kt headwind in 2-3 seconds. The worst of the turbulence lasted for approximately 5 seconds. The aircraft was then subject to light turbulence until able to climb to FL380 at 1237 hrs.

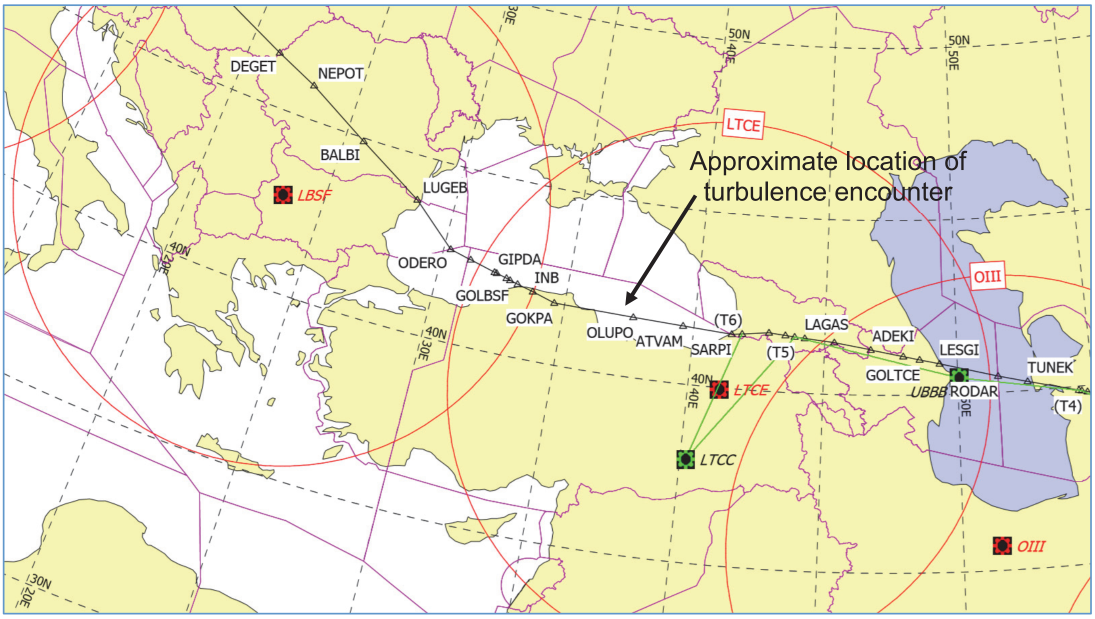

Figure 1

G-VFIT route through Turkey showing location of turbulence event

When the turbulence occurred the senior cabin crew member on duty made an announcement to reassure the passengers and to instruct the passengers and cabin crew to take their seats and fasten their seat belts.

After the aircraft was clear of the turbulence the commander was informed that a passenger in the rear galley had fallen over in the turbulence and had injured his ankle. The passenger was moved to a more comfortable seat and medical advice was obtained from a ground-based service provider[1].

The aircraft continued to Heathrow without further incident. A medical emergency was declared on arrival in the London FIR and a priority approach was requested and granted. On arrival, the aircraft was met by paramedics who treated the passenger. He was taken to hospital with a suspected broken ankle. He had surgery on his ankle the next day and was released from hospital seven days later.

One cabin crew member reported that he injured his shoulder when he fell against a bulkhead during the turbulence, but no medical treatment was required.

Footnote

1 Flight crew can contact the service in-flight, via satellite phone, to receive emergency medical advice from a doctor.

Passenger report

The injured passenger reported that he was waiting to use the toilet in the rear galley when the turbulence occurred. The seatbelt signs were OFF, and he recalled that he suddenly found himself lying on the floor not knowing what had happened. His right ankle was extremely painful and swelled up within a few seconds. A cabin crew member tried to get him to move back to his seat, but he was unable to get up. His wife and son helped him back to his seat and the cabin crew brought him an ice pack. Later the crew moved him to a seat with more space and gave him painkillers. However, his ankle continued to be extremely painful. After landing he was taken to hospital, where it was found that his ankle was dislocated and broken in two places.

Recorded data

The operator reviewed the available flight data which showed that at 1230 hrs the aircraft was at FL360 and Mach 0.82. The turbulence occurred at 1231:08 hrs with vertical acceleration varying between +0.64 g and +1.56 g, the speed increasing to Mach 0.86 and the aircraft rolled +/- 5°. The seatbelt signs were turned ON at 1232:57 hrs.

Meteorology

Forecast information available to the flight crew

Parts of the significant weather and wind charts issued to the flight crew prior to the flight are shown in Figures 2 and 3. The significant weather chart shows an area of isolated embedded cumulonimbus clouds with tops at FL320 in the area where the turbulence occurred. There was no clear air turbulence forecast in this area. The wind chart shows the wind circulating round a low pressure centred in north-west Turkey.

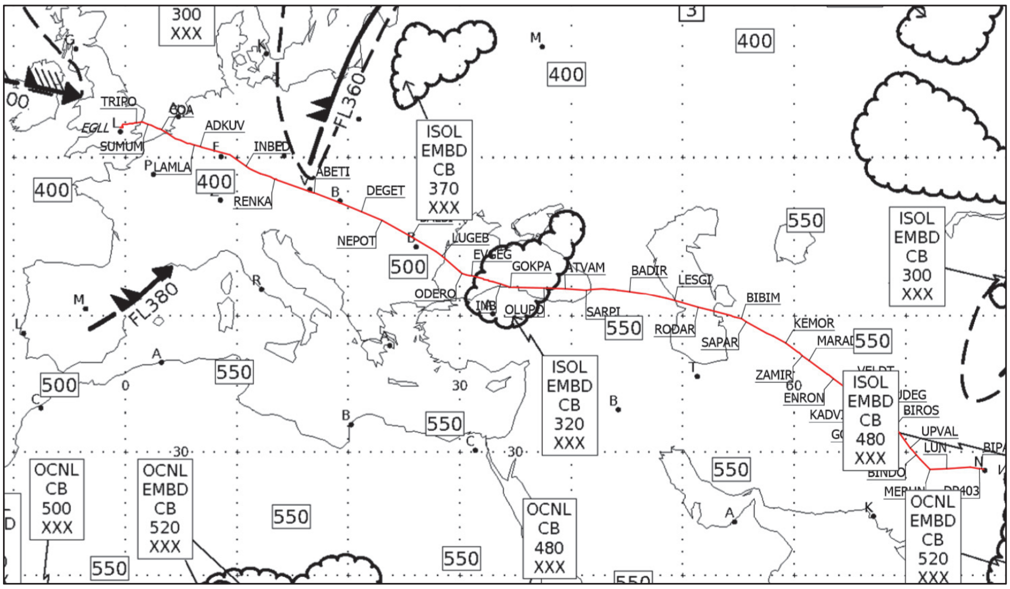

Figure 2

Segment of the significant weather chart valid at 1200 hrs on 21 August 2019

The significant weather chart included a note that cumulonimbus cloud implies moderate or severe turbulence. However, these clouds were below the cruise level of G-VFIT and the commander reported that the aircraft was clear of cloud when the turbulence occurred.

Ankara FIR had issued six SIGMETs[2], valid at the time of the turbulence event, which reported that thunderstorms had been observed in the area. There was no forecast or report of turbulence.

Flight plans issued to the flight crew provide forecast wind and temperature on the route which can give an indication of likely turbulence. The forecast wind at OLUPO was 202° at 63 kt; over the next 300 nm the wind was forecast to gradually change to an easterly wind. The temperature in this region at FL360 was forecast to be steadily decreasing from -43°C to -46°C. The plan also provided a forecast vertical shear rate in knots per 200 ft, which can indicate an area of turbulence. The value at OLUPO was one, increasing to four over the next 300 nm. The commander reported that shear values in single digits do not normally indicate significant turbulence.

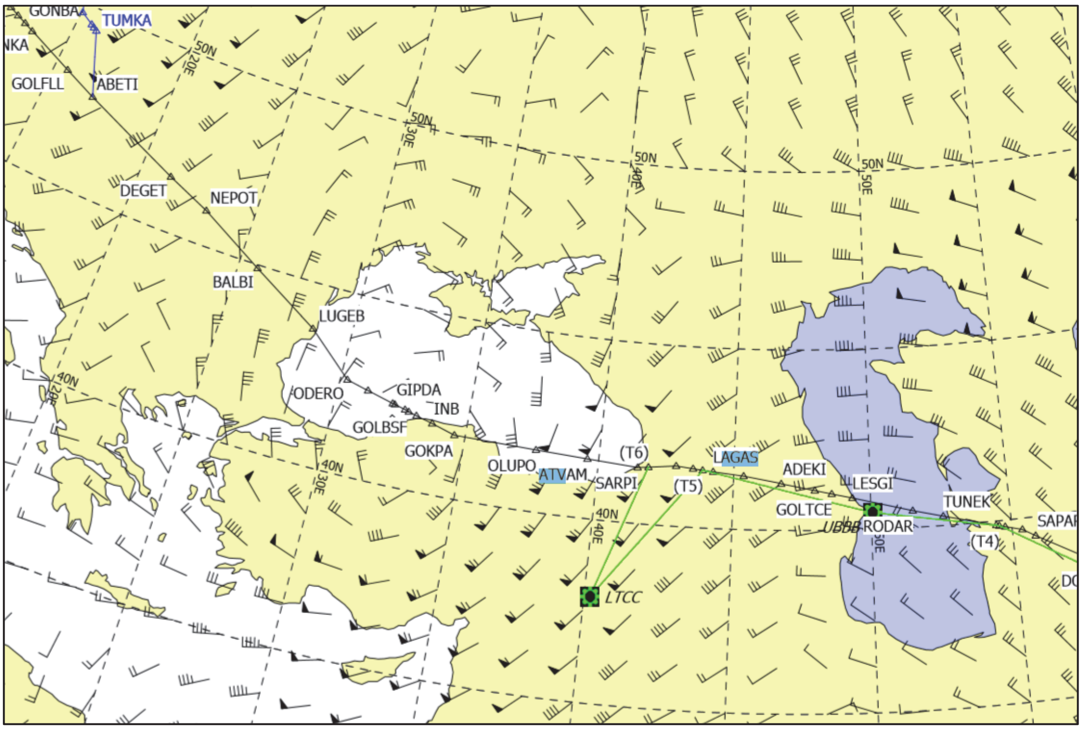

Figure 3

Segment of the wind chart valid at 1151 hrs on 21 August 2019

The flight crew used a charting application on their tablet devices which showed en route weather layers, forecast winds and areas of turbulence. The commander reported that

Footnote

2 A SIGMET (SIGnificant METrological information) is a notification of an en route weather phenomena which may affect the safety of aircraft operations.

the application did not show any turbulence in this area. At the time of the accident the operator only approved flight crew to upload data to the tablet on the ground, so it only contained the information available before the aircraft departed. Since the accident the operator has approved the use of the onboard WiFi system to update the application in-flight and to provide the most up-to-date information to the flight crew.

Aftercast weather

Figure 4 shows a derived satellite image showing cloud top heights at the time of the incident, produced by the Met Office after the accident. The image indicates there was a large area of cloud with tops between 30,000 ft and 35,000 ft across the area in question.

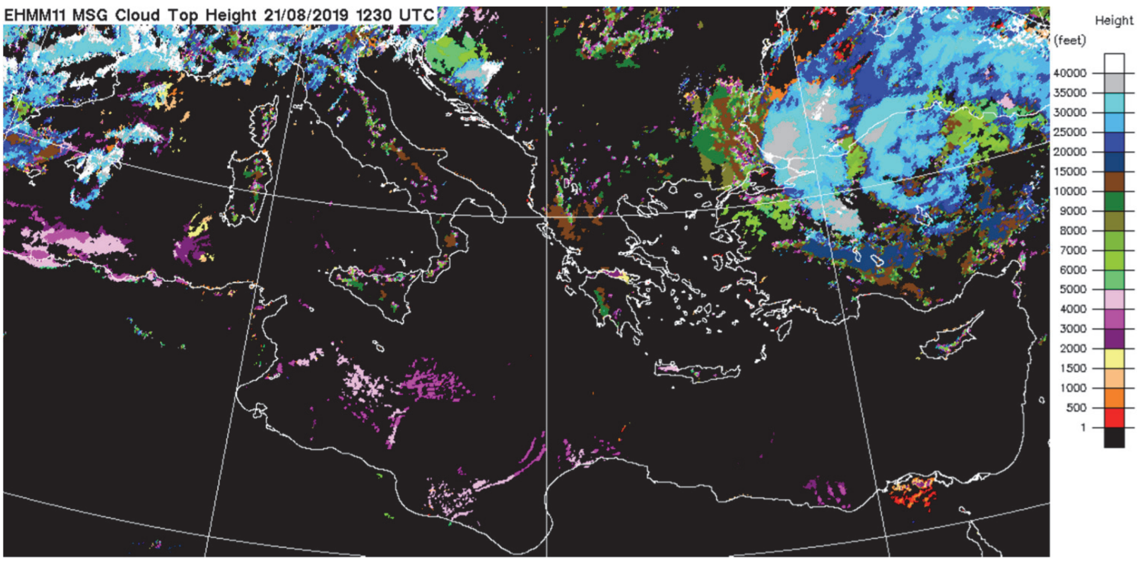

Figure 4

Derived Satellite Image showing Cloud Top Heights
valid at 1230 hrs on 21 August 2019

Seatbelt signs

The seatbelt signs were selected OFF when the turbulence occurred. Flight crew will normally turn the seatbelt signs ON if they anticipate turbulence, but on this occasion there was no indication that turbulence was likely to occur.

In general, flight crew face a difficult balance in deciding when to turn the seatbelt signs ON. If there are clear indications or reports of turbulence ahead, the signs can be turned ON in advance. However, if the flight crew put the signs on every time there is any chance of turbulence, it is likely the signs would be on for extended periods in smooth conditions, which can be frustrating for passengers. So, flight crew must balance the need to ensure the signs are on prior to any significant turbulence with the need to ensure the are not on unnecessarily.

Analysis

The aircraft encountered turbulence over northern Turkey during which a passenger was seriously injured. The turbulence was caused by a rapid wind shift.

There was no information available to the flight crew, either in the pre-flight paperwork, from the weather radar or visually to forewarn the flight crew that they were approaching an area of turbulence. Therefore, the seatbelt signs were OFF when they encountered the turbulence.

INCIDENT

Aircraft Type and Registration:	Boeing 737-8AS, EI-DPK
No & Type of Engines:	2 CFM56-7B27 turbofan engines
Year of Manufacture:	2007 (Serial no: 33610)
Date & Time (UTC):	26 February 2019 at approximately 1105 hrs
Location:	London Stansted Airport
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 6 Passengers - 169
Injuries:	Crew - None Passengers - 1 (Minor)
Nature of Damage:	None reported
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	39 years
Commander's Flying Experience:	5,000 hours (of which 1,800 were on type) Last 90 days - 236 hours Last 28 days - 85 hours
Information Source:	Aircraft Accident Report Form submitted by the operator and additional enquiries made by the AAIB

Synopsis

As passengers disembarked the aircraft using the forward integral airstairs, a child fell to the ground through the gap between the handrails. The child continued its journey without treatment after being assessed by medical personnel.

Boeing 737 forward airstairs

Some Boeing 737 series aircraft are fitted with a set of retractable airstairs at the forward left cabin door, to allow the boarding and disembarkation of passengers without the need for additional ground support equipment.

The airstairs include an integral two-rung handrail on either side. These rise into position during deployment of the stairs, but due to the geometric restrictions imposed by the retraction mechanism design, they do not extend to the fuselage side. In order to bridge this gap between the top of the handrails and the fuselage, a manually extendable handrail is fitted to each of the integral rails. After deployment of the airstairs, these are extended and secured to points in the entry door frame (Figure 1). Each extendable rail is supported by a strut extending from the side rail of the airstairs.

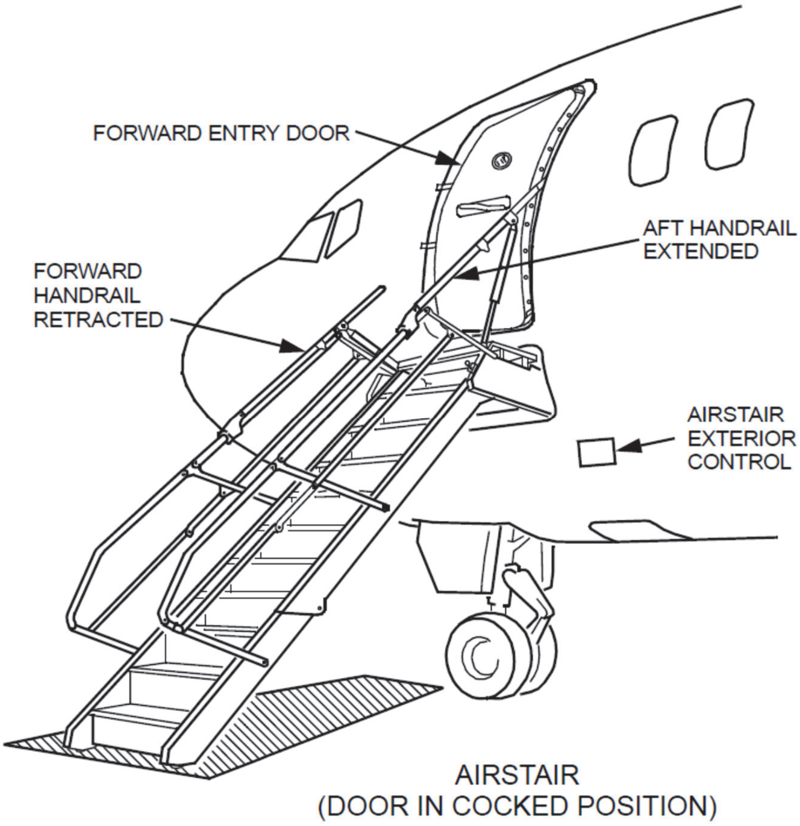

Figure 1

Boeing 737 forward airstairs

History of the flight and reporting of the event

The flight originated in Oslo and the passengers were disembarking on arrival in Stansted. It was daytime and weather conditions were reported to be dry. As a child left the aircraft with his family, he stumbled and fell sideways to the ground from the top two or three steps of the integral airstairs. The exact sequence of events leading to the fall was unclear, but the father reported that the child was walking while holding his hand. He felt the child pull from his hand and then fall sideways from the stairs. After assessment by airport medical personnel, the child was allowed to continue their journey without treatment.

The flight crew did not know that the child had fallen and, therefore, did not submit an Air Safety Report (ASR). The operator stated that their Customer Services department became aware of the fall in March 2019 when they received external correspondence relating to the event. In accordance with their internal procedures, they obtained reports from the ground crew and cabin crew, with the latter being reminded of the operator's procedures, which require that all inflight events are reported to the aircraft captain. The operator did not inform the AAIB because the child's injuries did not constitute an accident or serious incident as defined in ICAO Annex 13 or Regulation (EU) 996/2010. Irrespective of this, however, the event should have been reported to the Irish Aviation Authority (IAA) under Regulation (EU) 376/2014. This regulation requires the mandatory reporting of occurrences related to injury.

The AAIB became aware of the event in April 2019 and decided to investigate the circumstances under Article 5 of Regulation (EU) 996/2010. This decision was made in the knowledge of a previous similar event on EI-DLJ (AAIB Bulletin 8/2010) and the potential for a more serious outcome. The AAIB contacted the Air Accident Investigation Unit (AAIU) in Ireland, who subsequently contacted the operator's Safety Services Office. On becoming aware of the event, the Safety Services Office collated the cabin crew reports, processed an ASR, and submitted a Mandatory Occurrence Report to the IAA.

Investigation

The scope of the investigation was limited because the exact circumstances of the fall were unclear. There were four cabin crew on the flight, but none of them saw the child fall. The airport operator reviewed the CCTV footage, but the forward left door of the aircraft was outside the field of view and the fall was not recorded.

Previous events within Europe

The AAIB identified eight previously reported events in Europe since 2009 and six of these involved children of various ages. Typically, the airstair equipped Boeing 737 fleet completes over 780,000 flights per year, carrying over 120 million passengers across all age groups. The aircraft manufacturer confirmed that these events had been reported to them and reviewed in accordance with the Boeing / Federal Aviation Administration Continued Operational Safety Process. They considered that the existing safety actions provided adequate mitigation (see previous safety actions, below).

Certification of integral airstairs

Federal Aviation Regulation 25 and its European equivalent, Certification Standard 25, define the airworthiness standards for transport category aeroplanes. The specifications do not contain any requirements relating to integral airstairs. EASA advised that the Boeing 737-800 approval within Europe was issued by the Joint Aviation Authorities (JAA) following a validation activity in 1998. The integral airstair design is understood to have been accepted on the basis of previous Boeing 737 models.

Previous safety actions

Anti-skid material and warning placards

In September 2007, the Federal Aviation Administration issued a Special Airworthiness Information Bulletin (SAIB) after four reports of injuries resulting from small children falling through or over the airstair handrails[1]. The bulletin recommended the introduction of anti-skid material and warning placards to advise people accompanying children to hold the child's hand whilst on the stairs.

Footnote

[1] Special Airworthiness Information Bulletin NM-07-47 http://rgl.faa.gov/Regulatory_and_Guidance_Library/rgSAIB.nsf/dc7bd4f27e5f107486257221005f069d/cab005ca55f1abd78625734e006eb6b7/$FILE/NM-07-47.pdf (accessed 25 September 2019)

The operator of EI-DPK confirmed that warning placards and anti-slip material were in place on the aircraft when the child fell. In addition to these recommendations, after the previous AAIB investigation, the operator installed a retractable roller-tensioned tape and detachable airstair rails to further reduce the likelihood of somebody falling.

Boarding and disembarking announcements

The previous AAIB investigation resulted in Safety Recommendation 2010-018. This was made applicable to all UK operators of 737 aircraft with integral airstairs in April 2011 when the UK Civil Aviation Authority issued a Safety Notice (SN-2011/02) entitled '*Safe Use of Airstairs*.' The safety notice required operators to review their boarding and disembarkation procedures so that special assistance is made available to passengers accompanied by small children, or those with special needs. The notice stated that operators:

> *'should also review announcements made by staff at the boarding gate and before disembarkation to ensure that passengers' attention is drawn to the need to exercise caution when boarding and disembarking using airstairs. Passengers in these circumstances should, in particular, be advised to keep small children under close supervision throughout the boarding and disembarkation process.'*

This Safety Notice was cancelled in 2018.

The operator's ground operations manual contains the pre-boarding announcement, which includes the words:

> *'adults with young children must hold their hands whilst walking to the aircraft and on the aircraft steps. Use the handrails provided.'*

The Safety Equipment Procedures manual contains the before disembarking announcement, which contains the words:

> *'All passengers should use the handrail provided when walking down the stairs. For passengers travelling with children please hold their hands as you walk down the stairs and until you are inside the terminal building.'*

Discussion

The child continued his journey without medical treatment, so the event did not meet the criteria of an accident or serious incident defined in ICAO Annex 13 or Regulation (EU) 996/2010. However, the investigation was instituted because safety lessons were expected to be drawn from it.

The flight crew were unaware of the fall, which occurred within the defined period of a flight. The operator reminded their cabin crew that their incident reporting procedures requires them to notify the aircraft captain of events that occur in flight. If appropriate, the flight crew will submit an ASR and the regulator can be notified if necessary. In the case of this event, there was a mandatory requirement to notify the IAA under Regulation (EU) 376/2014. In this case there was a delay of approximately two months because the flight crew were unaware of the fall.

There are no certification requirements for integral airstairs and in the last 10 years, there have been nine reports (within Europe) where people, both adults and children, have fallen whilst using them. The manufacturer is aware of these events and considers the recommendations in the FAA SAIB to be adequate mitigation. When considering the arising rate, the operator reported that in 2018, they completed over 787,000 flights and carried over 126 million passengers across all age groups.

INCIDENT

Aircraft Type and Registration:	Boeing 777-36, G-STBB
No & Type of Engines:	2 General Electric Co GE90-115B turbofan engines
Year of Manufacture:	2010 (Serial no: 38286)
Date & Time (UTC):	24 August 2019 at 1740 hrs
Location:	En route from London Heathrow Airport to JFK Airport, New York
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 17 Passengers - 302
Injuries:	Crew - None Passengers - None
Nature of Damage:	Burnt out oven motor in aft galley
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	53 years
Commander's Flying Experience:	13,899 hours (of which 4,827 were on type) Last 90 days - 173 hours Last 28 days - 39 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

Whilst in the initial part of the cruise, the captain was called by the senior cabin crew member informing him that there was a suspected fire in the aft galley. Shortly afterwards the cabin crew member confirmed that blue smoke was emanating from the oven unit. The cabin crew carried out their fire drill and the flight crew completed the 'smoke, fire or fumes' checklist. The flight crew then informed ATC of the event.

After electrically isolating the aft galley the rate of smoke production reduced; however, smoke remained in the area. The captain made the decision to divert to Shannon, where an uneventful overweight landing and disembarkation took place. There were no injuries to any of the passengers.

Examination of the aft galley oven by the operator's engineers found that an electrical fault in an oven fan unit had caused the smoke. The fan unit was replaced and the aircraft returned to service. No further investigation of the oven fan unit was conducted by the operator.

ACCIDENT

Aircraft Type and Registration:	Piper PA-28R-201T Turbo Cherokee Arrow III, G-DDAY
No & Type of Engines:	1 Continental Motors Corp TSIO-360-F piston engine
Year of Manufacture:	1977 (Serial no: 28R-7703112)
Date & Time (UTC):	22 October 2019 at 1400 hrs
Location:	Nottingham Airport
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - 1
Injuries:	Crew - None Passengers - 1 (Minor)
Nature of Damage:	Damaged beyond economic repair
Commander's Licence:	Private Pilot's Licence
Commander's Age:	69 years
Commander's Flying Experience:	240 hours (of which 91 were on type) Last 90 days - 0 hours Last 28 days - 0 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

The pilot, with a passenger, was conducting a 90-day, three takeoffs and landings revalidation and had completed two of these without incident. The weather was good, and the wind was from 230° at 10 kt.

On the third landing, the aircraft touched down on Runway 21 'on the numbers'; the pilot reduced flap to two stages and selected full throttle. Directional control was lost, and the aircraft veered off the runway to the left and became airborne just as the propeller contacted rough ground.

The aircraft became difficult to control and the pilot flew a low downwind leg to return to the airfield. Once within the airfield boundary, the aircraft became uncontrollable and it struck the ground just north of Runway 27 incurring substantial damage.

Both pilot and passenger were wearing lap and diagonal harnesses and only the passenger suffered minor injuries. The reason for the loss of directional control is not known.

AAIB Record-Only Investigations

This section provides details of accidents and incidents which were not subject to a Field or full Correspondence Investigation.

They are wholly, or largely, based on information provided by the aircraft commander at the time of reporting and in some cases additional information from other sources.

The accuracy of the information provided cannot be assured.

Record-only investigations reviewed November - December 2019

13-May-19 **Pioneer 300** **G-OWBA** Oxenhope Airfield

The aircraft floated in the flare and landed half-way along the runway following a higher than normal approach. The pilot was unable to stop the aircraft before reaching the end of the runway.

06-Jul-19 **Robinson R22 Beta** **G-WINR** Princes Risborough

The student pilot accidentally shut down the engine by moving the mixture lever rather than the carburettor heat. Autorotation into a field was successful, but the helicopter rolled onto its side after touchdown due to uneven ground.

06-Aug-19 **Rotorway Executive 90** **G-BVOY** Deenethorpe Airfield

While taxiing out-of-wind the tail of the helicopter was lifted by a gust and the front of a skid caught the ground, causing the helicopter to roll over.

21-Aug-19 **Piper PA-17 Vagabond** **G-ALIJ** Shoreham Airport

The aircraft veered to the left unexpectedly after touchdown. When the pilot attempted to brake and correct, the aircraft tipped onto its nose.

25-Aug-19 **DH82A Tiger Moth** **G-AYDI** Lodge Farm House, Wantage Oxfordshire

During landing a crosswind gust caused the aircraft to veer to the right. The right wheel and wing contacted the ground and caused the aircraft to flip over damaging the propeller, rudder, fin and lower mainplane.

12-Sep-19 **Jabiru SK** **G-BYBZ** Private airstrip, Durham

The aircraft landed off the centre line. The main landing gear caught the long grass and the aircraft left the runway at low speed.

03-Nov-19 **Morane Saulnier Rallye 150ST** **G-BERA** Redhill Aerodrome, Surrey

The aircraft departed the runway edge on landing and hit a marker board causing minor damage to the trailing edge of the left flap.

18-Nov-19 **Cessna 172M** **G-EGLA** Bodmin Airfield

The aircraft collided with a fence during a runway excursion on landing, suffering minor damage. It is reported to have landed long and fast.

20-Nov-19 **Grob G115** **G-CIMI** Leicester Aerodrome

The aircraft landed long on Runway 15 and ran off the end before stopping.

Record-only investigations reviewed November - December 2019 cont

02-Dec-19 **Europa** **G-MFHI** Rochester Airport

During taxi after landing the nose gear collapsed. The propeller and nose landing gear were damaged. There were no injuries.

04-Dec-19 **Sherwood Kub (SSDR)** **G-TLEE** Egerton Airfield, Kent

During the takeoff run the nosewheel dug into the grass runway and broke causing the aircraft to flip over.

07-Dec-19 **Cessna 150F** **G-ATHV** Warrington Grass Airfield

During taxi the aircraft slid on wet grass and the port main wheel and nosewheel slipped into a drainage ditch resulting in damage to the port wingtip, port tailplane and the propeller.

31-Dec-19 **Savannah Jabiru** **G-CDLR** Widdrington, Northumberland

Whilst carrying out a practice forced landing the engine failed. During the subsequent forced landing in a field the nosewheel dug into soft ground and the aircraft flipped inverted.

Miscellaneous

This section contains Addenda, Corrections and a list of the ten most recent Aircraft Accident ('Formal') Reports published by the AAIB.

The complete reports can be downloaded from the AAIB website (www.aaib.gov.uk).

BULLETIN CORRECTION

Aircraft Type and Registration:	Champion Citabria, G-AYXU
Date & Time (UTC):	15 September 2019
Location:	Gloucester Airport
Information Source:	Record only investigation

AAIB Bulletin No 12/2019, page 92 refers

The original entry was incorrect in that it stated 'The nosewheel collapsed after landing'. The entry has since been corrected to read:

> On landing directional control was lost resulting in a ground loop, which collapsed the left hand undercarriage resulting in substantial damage to the wing and propeller. The aircraft has been written off.

The online version of the report was corrected on 9 January 2020.

BULLETIN CORRECTION

Aircraft Type and Registration:	DH82A Tiger Moth, G-ANDP
Date & Time (UTC):	9 September 2019
Location:	Ballymagreehan, Newtownards, County Down
Information Source:	Record only investigation

AAIB Bulletin No 12/2019, page 92 refers

The original entry was incorrect in that it stated that the aircraft landed back on the strip but struck a boundary fence. This should have read and struck a boundary fence. The entry has been amended to read:

> The aircraft failed to achieve climb performance after takeoff but landed back on the strip **and** struck a boundary fence.

The online version of the report was corrected on 9 January 2020.

BULLETIN CORRECTION

Aircraft Type and Registration:	Guimbal Cabri G2 G-CHWJ
Date & Time (UTC):	7 May 2019
Location:	Cotswold Airport
Information Source:	Record only investigation

AAIB Bulletin No 12/2019, page 89 refers

The original entry was incorrect in that it stated that the incident occurred on 4 July 2019, when in fact it was the **7 May 2019**.

The online version of the report was corrected on 9 January 2020.

BULLETIN CORRECTION

Aircraft Type and Registration:	Mainair Blade 912, G-BYTU
Date & Time (UTC):	18 October 2019
Location:	Chirk Airfield, Wrexham
Information Source:	Record only investigation

AAIB Bulletin No 12/2019, page 93 refers

The report incorrectly states that the accident occurred at Clacton Airfield. The accident occurred at Chirk Airfield, Wrexham.

The pilot has also reported that, during the deceleration on wet uneven ground, the aircraft yawed with increasing severity to the right which caused the right wing to strike the ground.

The online version of the report was corrected on 9 January 2020.

SUPPLEMENT

Registered Owner and Operator	Canfield Hunter Ltd
Aircraft Type	Hawker Hunter T7
Nationality	British
Registration	G-BXFI
Place of accident	A27, Shoreham Bypass, at the junction with Old Shoreham Road, North of Shoreham Airport
Date and Time:	22 August 2015 at 1222 hrs (Times in this report are UTC[1] unless stated otherwise)

Summary

In June 2019 the AAIB was asked to consider additional information related to the accident involving Hawker Hunter G-BXFI at Shoreham in 2015. As part of its review of this material the AAIB considered further aeromedical opinion and produced more detailed estimates of acceleration experienced by the pilot in the manoeuvres preceding the accident. The review concluded that the findings of the AAIB investigation published in Aircraft Accident Report 1/2017 remain valid.

Introduction

On 3 March 2017 the AAIB published the final report[2] of its investigation of the accident involving Hawker Hunter G-BXFI near Shoreham Airport on 22 August 2015 (the AAIB investigation). In the period between June and October 2019 the AAIB was asked to consider additional information. This included witness statements, several analyses[3] of the pilot's actions and a video of a practice display at Duxford. The purpose of this review was to determine if these documents contained new and significant evidence of cognitive impairment.

For the purpose of this review, the AAIB defined cognitive impairment as a physiological state in which an individual cannot think as well as usual, so is less able to do a task reliably and the probability of error is increased.

The review considered whether the material was:

- evidence – containing facts relevant to the accident, distinct from analysis of those facts,

Footnote

1 Co-ordinated Universal Time.
2 Aircraft Accident Report 1/2017: report on the accident to Hawker Hunter T7, G-BXFI near Shoreham Airport on 22 August 2015 available at https://www.gov.uk/aaib-reports/aircraft-accident-report-aar-1-2017-g-bxfi-22-august-2015 [accessed December 2019]
3 These analyses were prepared for a purpose other than safety investigation and do not necessarily represent the complete opinion of their authors.

- new – not previously considered by the AAIB, and
- significant – having a different effect from evidence that the AAIB had already considered.

If all three criteria were met, the AAIB was required to reopen its investigation.[4]

The review involved Inspectors who were not part of the AAIB investigation described in Aircraft Accident Report 1/2017. The review team included an Inspector (Human Factors), an Inspector (Recorded Data) with expertise in aircraft performance, and two Inspectors (Operations) who were formerly fast jet pilots with experience in instruction and display flying.

As part of the process of considering the significance of the material presented, the review applied additional modelling techniques to determine the aircraft's flight path, and to provide more detailed estimates of +Gz (the "head to foot" acceleration experienced by the pilot, normal to the flightpath), in the manoeuvres preceding the accident. These are described in Appendix 1. It also considered additional aeromedical opinion.

Summary of Gz analysis

The additional modelling indicated that +Gz during the positioning turn was briefly about 3.8 g, four seconds after the start of the positioning turn, falling within three seconds to approximately 2.2 g, then rising slightly to a level predominantly around 3 g before falling again to around 1 g over the final six seconds of the turn.

The review also estimated +Gz exposure in the first part of the loop. This indicated that a maximum +Gz of 4 g occurred about five seconds after the start of the manoeuvre and remained above 3 g for about four seconds. The +Gz load then reduced in a linear manner to a value of approximately 1.6 g some four seconds later.

Conclusions of the AAIB investigation regarding pilot impairment

The issue of possible cognitive impairment due to +Gz exposure was considered in the AAIB investigation and was discussed in the AAIB final report[5]. The pilot's behaviour as captured by a cockpit action camera[6] was assessed by pilot expert advisors to the investigation, human factors experts and an aeromedical expert. The AAIB report stated:

> *'As far as could be determined from cockpit image recordings the pilot appeared alert and active throughout the flight.'*

Footnote

[4] Regulation 18(1) of the Civil Aviation (Investigation of Air Accidents and Incidents) Regulations 2018.
[5] See sections 1.18.10.1 page 124 and 2.2.3 page 166 of AAIB Aircraft Accident Report 1/2017.
[6] This camera captured a partial view of the pilot from behind, a portion of the instrument panel and a portion of the view through the canopy and windscreen. See section 1.11.3 page 40 of AAIB Aircraft Accident Report 1/2017.

The aeromedical expert who advised the AAIB investigation stated:

> *'Although some day to day variation in G tolerance occurs in every individual, it would be very unusual for an individual to suffer G related impairment at less than +3Gz while wearing a G suit. The video evidence reviewed herein shows no evidence of the classically described G-LOC or A-LOC syndromes, and the G levels in the accident video are similar to previously experienced levels flown without incident (eg in the Duxford video).*[7] *Therefore, I can find no evidence of G related impairment in the material available for review.'*

The pilot had G currency[8] having flown nine displays in the two weeks prior to the accident. Although not documented in detail in the AAIB final report, other factors that can affect G tolerance[9] were considered to the extent possible using information from the accident flight and previous flights conducted by this pilot, medical information and pilot interviews. There was no evidence that these factors differed significantly from previous occasions.

The AAIB report provided the following analysis of the factual information it presented:

> *'There was no evidence of any g-related impairment of the pilot during the aerobatic sequence flown. If the pilot was unwell before the accident, it was not established in what way he was unwell or when the onset of any condition was first experienced.'*

On this topic, the report concluded that:

> *'The g experienced by the pilot during the manoeuvre was probably not a factor in the accident.'*

Analysis of pilot actions - AAIB investigation

The pilot's actions were considered during the AAIB investigation. Evidence was limited because the pilot did not recall the accident and his plan for the display was not documented in detail. It was not possible to draw firm conclusions about what influenced the pilot's performance on the day.

The AAIB's analysis focused on two decision points where the pilot may have been able to recover from any deviations in the planned manoeuvres that had occurred and prevent the situation from progressing into an accident:

1. The entry to the accident manoeuvre
2. The apex of the accident manoeuvre

Footnote

7 Cockpit image recording of a display at Duxford.
8 Recent experience of flying with +Gz exposure. G currency increases G tolerance.
9 Factors reducing G tolerance include hypoxia, hyperventilation, infection, drugs, alcohol, heat stress, dehydration, fatigue, hunger and poor physical fitness among others. Factors increasing G tolerance include G currency, use of anti-G clothing and anti-G straining manoeuvre among others.

The AAIB determined that these were the areas where the greatest safety learning could be obtained to improve display pilots' ability to recover when manoeuvres do not progress as planned.

The Royal Air Force Centre for Aviation Medicine (RAFCAM) conducted a human factors analysis[10] of these decision points. It used a range of evidence sources such as the cockpit action camera footage, results from flight trials and notes from interviews with the pilot. The RAFCAM applied recognised systematic human factors analysis techniques.[11] The RAFCAM analysis identified the credible errors and performance shaping factors[12] that could have been present at the entry to the loop manoeuvre, during the climb and at the apex of the manoeuvre.

Additional analyses of the pilot's actions

The material presented to the AAIB in 2019 included analyses by six different authors of the pilot's actions preceding the accident. Among them the authors had experience and qualifications in display flying, aviation medicine and human factors. None of these documents were 'evidence'. They were all opinions regarding the pilot's actions based on the authors' interpretations of facts that were already known to the AAIB. These analyses of the pilot's actions were reviewed to determine if they contained or referenced new and significant evidence, or if they offered new insights.

Figure 1 summarises how the analyses considered that the pilot's performance diverged from what was required.

Several of the authors asserted that such a pattern of behaviour by this pilot could only be explained by some form of cognitive impairment. One of the authors argued that the only source of such impairment possible in this accident was +Gz.

Referenced research papers

One of the documents referred to several published papers on the topic of human response to +Gz. These papers were evidence that was potentially relevant and had not been considered previously by the AAIB (Appendix 2 provides summaries). Therefore, they were considered as part of this review to assess whether they were significant. Only those papers referenced within the documents presented to the AAIB have been considered specifically.

Footnote

10 *Royal Airforce Centre for Aviation Medicine. Aircraft Accident Human Factors Report. Hawker Hunter G-BXFI. Shoreham Airshow, 22 August 2014.* Referred to in Appendix M, pages 404 – 420 of the AAIB Aircraft Accident Report 1/2017.

11 Task analysis and two methods of human error analysis, Systematic Human Error Reduction and Prediction Approach (SHERPA) and an adapted version of the Australian Transportation Safety Board Human Factors analysis of see and avoid.

12 Performance shaping factors are characteristics of an individual, group, task, environment or organisation that influence human performance. Some performance shaping factors enhance performance, such as motivation, training or practice and some reduce human performance such as high workload, unclear procedures or badly designed equipment.

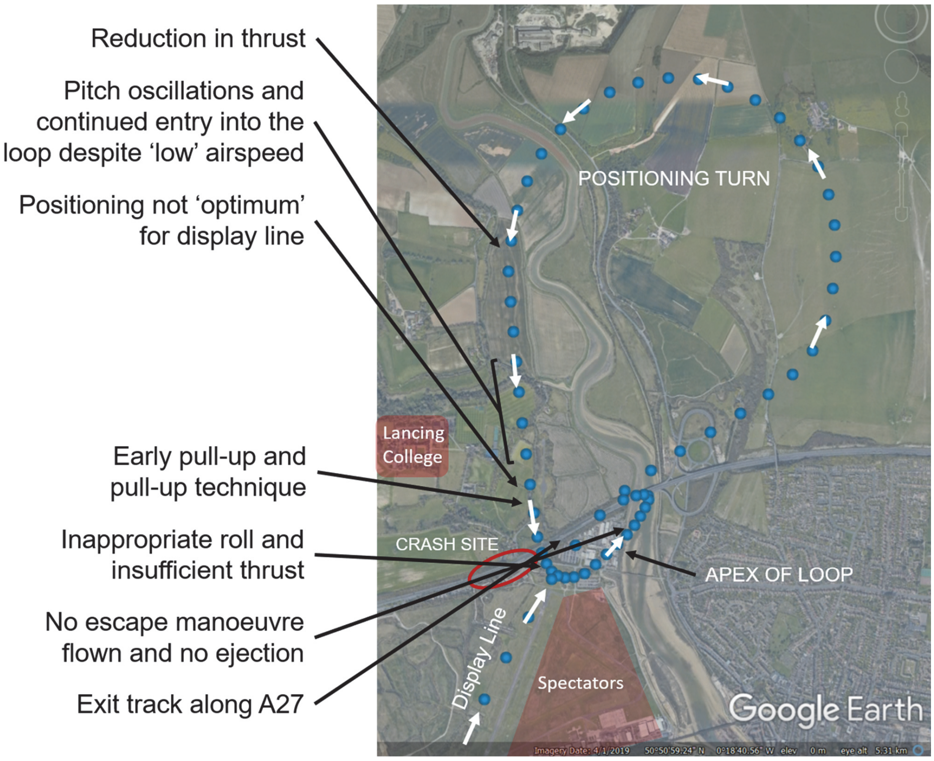

Figure 1

Summary of pilot actions according to material provided to the AAIB

There are other published academic papers that also cover this topic. It was outside the scope of this review to search the wider literature, but additional aeromedical opinions were invited so that current scientific consensus could be considered.

General aeromedical information regarding +Gz tolerance

As part of this review, the AAIB requested further aeromedical opinion from two external experts[13], who considered the more detailed Gz profile and cockpit action camera footage. Both experts were qualified aviation medical practitioners with a specialism in G-related physiology and the effects on human performance of G exposure.

The AAIB also consulted standard texts[14] regarding the effects of G on human performance. The following definitions are relevant:

- Greyout is the partial loss of vision. Sometimes referred to as partial light loss.
- Blackout is the complete loss of vision with preserved consciousness. Sometimes referred to as light loss.

Footnote

[13] The aeromedical experts were from different organisations, one in the UK and one in another State.

[14] Gradwell, D.P. and Rainford, D.J. (2016). *Ernsting's Aviation and Space Medicine. 5th edition.* CRC press. Green, N., Gaydos, S., Hutchison, E. and Nicol, E. (2019). *Handbook of Aviation and Space Medicine.* CRC press Reinhart, R.O. (2008). *Basic Flight Physiology. 3rd edition.* McGraw-Hill.

- A-LOC is 'almost loss of consciousness'. It is G-related incapacitation without overt loss of consciousness. There is inconsistency in the literature about the performance effects, but symptoms reported following A-LOC include sensory abnormalities, amnesia, confusion and a disconnection between cognition and the ability to act.
- G-LOC is 'G induced loss of consciousness'. It features a period of absolute incapacitation followed by a period of impaired consciousness while the crew member is recovering.
- G tolerance is the level at which individuals experience greyout or G-LOC. It varies between individuals and there is variation within individuals on different days.

The figures stated for average levels of Gz tolerance varied slightly in the literature depending on what research source was used. Figure 2 summarises results from a compilation of Gz tolerance studies involving participants who were not wearing any anti-G clothing or performing any techniques to increase their G tolerance. Each point on the graph shows the result of a research study in terms of when the end point of greyout, blackout or unconsciousness was experienced under different levels of Gz and different durations of exposure. The line on the graph summarises the general finding seen across studies that high levels of Gz of short duration may not result in symptoms, but symptoms progress quickly if the onset of Gz is rapid. Lower levels can be tolerated for longer, especially if the onset is slow. It shows that it is rare to find effects within four seconds of exposure or below +3 g.

A typical G-suit could provide up to 1.5 g additional tolerance if working correctly. Wearing anti-G clothing even if not functional is said to add approximately 0.4 g additional tolerance.[15]

Greyout, blackout, A-LOC and G-LOC are the only performance effects of +Gz that are widely acknowledged by the aeromedical community. None of the standard texts mentioned a possibility of cognitive impairment at low levels of +Gz exposure insufficient to induce A-LOC or G-LOC.

The two aeromedical experts were specifically asked about performance effects of low +Gz exposure. They provided opinion supported by published literature, a bibliography of which is included at the end of this supplement.

One expert stated:

> *'Some limited research has been conducted looking at cognitive impairment under +Gz loads that do not result in A-LOC or G-LOC. The findings of these studies are somewhat inconsistent, and in many cases contradictory. As such, it is not possible to make definitive conclusions from these limited experimental studies, which by and large have no practical implications for the flying task under +Gz.'*

Footnote

[15] Parkhurst, MJ, Leverett SD Jr, Shubrooks JR. *Human Tolerance to High, Sustained +Gz Acceleration*. Aerospace Med. 1972; 43(7):708712.

The other expert cited three studies that found no change in performance under low levels of +Gz and two studies that found some minor changes in performance during or after +Gz exposure. In conclusion this expert stated:

> *'Based on the limited evidence that does exist, and international medical and flying experience, the probability that pilots can become cognitively impaired during exposure to low levels of +Gz acceleration is extremely low.'*

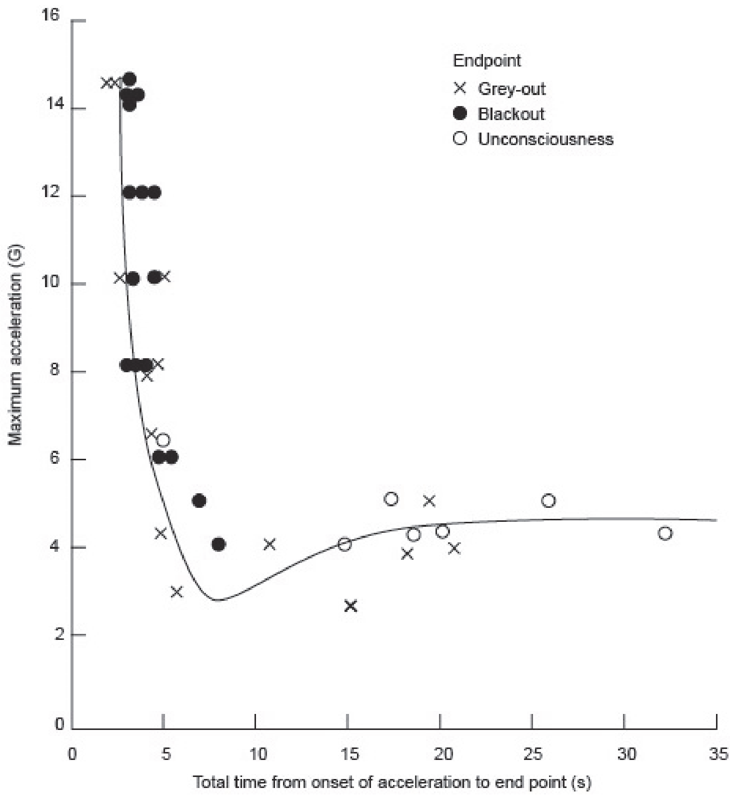

Figure 2

Relaxed participants' tolerance to +Gz acceleration based on a compilation of research studies (reproduced from Gradwell, D.P. and Rainford, D.J., 2016)

The AAIB reviewed the full original text of all the publications cited by the aeromedical experts.

It also asked the opinion of the RAFCAM, which advised the AAIB that:

> *'the existence of low Gz induced cognitive impairment is not supported by decades of flight experience or flying training under high G loads requiring completion of complex cognitive tasks.'*

The RAFCAM consulted the relevant NATO panel, air forces in the European Air Group, the Five Eyes Air Force Interoperability Council, and the United States Air Force. None of these authorities recognised the existence of low Gz-induced cognitive impairment, nor do they train their respective military pilots to avoid this condition.

Re-assessment of video footage

During this review, videos of the accident flight and previous displays and practises by the pilot at Shoreham in 2014, Duxford 2014, Bray 2015, Shuttleworth 2015 and Eastbourne in 2014 and 2015 were re-examined by two AAIB Inspectors of Air Accidents (Operations). Their experience included flying, displaying and instructing in various aircraft types including the Jet Provost, Hawk, Buccaneer, Hunter, Jaguar and T33 Shooting Star. They were not part of the AAIB investigation team.

These Inspectors, familiar with observing students while sat behind them in tandem cockpits, concluded that the pilot's head and body movements were consistent with what they would expect from someone flying a loop manoeuvre. They did not observe any significant differences in behaviour between the accident flight and previous displays. They could not identify a point at which the pilot's behaviour changed in an observable way that would indicate impairment.

One of the aeromedical experts reviewed the cockpit action camera footage of the accident flight and the Shoreham display in 2014 for evidence of +Gz induced impairment. He stated:

> *'the accident clip does not demonstrate any of the typical head movements associated with impairment due to high +Gz.'*

Figure 3 and Figure 4 illustrate one of the behaviours he described as an example of optokinetic cervical reflex.[16,17,18,19] This is a well-documented phenomenon in low-level flight in visual meteorological conditions, in which a pilot orients their head with respect to the visible horizon rather than the aircraft's attitude. This aeromedical expert noted that:

> *'the presence of these typical flight-related head movements is entirely consistent with normal, routine flight operations.'*

He concluded that:

> *'there was no discernible significant difference between the head movements of the pilot in either of the two flights. What movements were seen were entirely consistent with a pilot attempting to maintain an adequate lookout during low-level aerobatic manoeuvring.'*

Footnote

[16] Beer J, Freeman, D. Flight display dynamics and compensatory head movements in pilots. Aviat Space Environ Med 2007; 78(6):579-87.

[17] Gallimore J BN. Effects of FOV and Aircraft Bank on Pilot Head Movement and Reversal Errors During Simulated Flight. Aviat Space Environ Med 1999; 70:1152-60.

[18] Gallimore J P, F, Brannon, N, Nalepka, J. The Opto-Kinetic Cervical Reflex During Formation Flight. Aviat Space Environ Med 2000; 71(8):812-21.

[19] Merryman R, Cacioppo, A. The Optokinetic Cervical Reflex in Pilots of High-Performance Aircraft. Aviat Space Environ Med 1997; 68(6):479-87.

Figure 3

Shoreham 2014: Head movement example of optokinetic cervical reflex

Figure 4

Accident flight: Head movement example of optokinetic cervical reflex

Analysis

The AAIB investigation considered the possibility of G-related pilot impairment. The final report included an approximate calculation of +Gz in the turn preceding the accident manoeuvre, analysis of the pilot behaviour from the cockpit action camera and expert aeromedical opinion. Given the relatively low levels of +Gz and the absence of any signs of impairment, the investigation concluded that '*The g experienced by the pilot during the manoeuvre was probably not a factor in the accident*'[20], though it could not be ruled out.

Footnote

[20] Finding 31, page 197 of AAIB Aircraft Accident Report 1/2017.

The issue was raised again by additional information provided to the AAIB, which included analyses by other authors that differed from analysis presented in the AAIB final report. None of the information was assessed to be new and significant evidence but the review provided an opportunity to consider the possibility of +Gz impairment in more depth in case further safety learning could be obtained.

Exposure to Gz

As part of the review, the cockpit video recordings and other evidence were analysed further[21] to model +Gz exposure during the positioning turn. This provided additional detail for the manoeuvres preceding the accident. Calculated +Gz for the positioning turn was briefly about 3.8 g, four seconds after the start of the positioning turn, reducing within 3 seconds to approximately 2.2 g, then rising slightly to a level predominantly around 3 g before falling again to around 1 g over the final six seconds of the turn.

The review also estimated +Gz exposure in the first part of the loop. This indicated that a maximum +Gz of 4 g occurred about 5 seconds after the start of the manoeuvre. The G-onset rate peaked at 0.8 g/s with +Gz remaining above 3 g for about 4 seconds. The +Gz load then reduced in a linear manner to a value of approximately 1.6 g some four seconds later.

These calculations show how +Gz developed over time. When compared to aeromedical information about human G tolerance it shows that the forces experienced were outside the range usually considered a hazard to human performance. The literature cited in the additional material provided to the AAIB (summarised in Appendix 2) was consistent with this aeromedical consensus. It generally related to +Gz levels greater than those experienced in the accident or was based solely on pilot recollections without empirical measurement.

The forces experienced on the accident flight were unlikely to have affected the pilot considering his aerobatic currency and the protection of the G-suit. The more detailed analysis of the flight path and Gz in this review adds weight to the AAIB investigation's finding that G-related impairment was probably not a factor.

Cognitive impairment by +Gz

The cockpit action camera footage showed that the pilot was active throughout the flight. He appeared to be controlling the aircraft and using a variety of cues as would be expected for the manoeuvres flown. Some of the documents submitted to the AAIB asserted it is possible the pilot suffered cognitive impairment so subtle as to be not observable in the video footage or conduct of the task. Subtle cognitive impairment by +Gz has not been considered an issue within aviation even though G-related visual symptoms were first recorded in 1920[22]. It is not recognised by the aeromedical community in general

Footnote

[21] See Appendix 1.
[22] Head, H. (1920). The Sense and Stability of Balance in the Air. In Medical Research Council Report into the Medical Problems of Flying. London HM Stationary Office 1920: 214 - 56 cited in Gradwell, D.P. and Rainford, D.J. (2016). Ernsting's Aviation and Space Medicine. 5th edition. CRC press.

and major military authorities around the world do not consider it to be an issue. Both aeromedical experts consulted during this review considered it unlikely, basing their view on the balance of published evidence of which they were aware. Where performance effects were documented in these published studies, their direction, nature and magnitude were variable, and some studies found no change in the performance variables they measured. There were not enough studies of low +Gz exposure overall to draw conclusions about any particular performance effect.

It was outside the scope of this review to perform a comprehensive search of the literature and there may be additional relevant material that has not been considered. The UK Civil Aviation Authority (CAA) stated that it is conducting a medical review of the potential risk of cognitive impairment in civilian pilots due to G forces. It will not re-examine the specific circumstances of the 2015 Shoreham accident. Following this review and if appropriate, the CAA will consider taking regulatory action to improve flight safety.

Performance shaping factors

Some of the analyses provided to the AAIB offered an account of where in the accident flight the authors felt the pilot's actions differed from what was intended or appropriate. Not all these actions were discussed in the AAIB final report due to limited evidence about the pilot's intentions and a focus on areas where safety could be improved. Some of the authors of the additional material considered in this review asserted that, looking at the pilot's overall pattern of behaviour, impairment was the only explanation. However, there are alternative explanations that do not involve cognitive impairment.

It is possible that an individual doing any task will do it incorrectly. For an easy task or a highly trained person doing a task they are very familiar with, the likelihood of this is low. For a difficult task, or a task performed by someone not sufficiently familiar with it, the likelihood is high. The probability that someone will do a task incorrectly is influenced by performance shaping factors. Impairment was one possible performance shaping factor in the G-BXFI accident. The AAIB investigation found no evidence of impairment but, if present, it did not affect the pilot's observable behaviour and the source of any impairment was unknown.

Other performance shaping factors were more likely than impairment to have contributed to this accident. During the AAIB investigation, the RAFCAM conducted a human factors analysis.[23] It identified credible performance shaping factors, including the possibility of glare affecting the pilot's ability to read critical information from the instruments, and the possibility that the pilot did not correctly recall the required speeds and heights due to the differences between the various aircraft he regularly flew.

Footnote

[23] *Royal Airforce Centre for Aviation Medicine. Aircraft Accident Human Factors Report. Hawker Hunter G-BXFI. Shoreham Airshow, 22 August 2014.* Referred to in Appendix M, pages 404 – 420 of the AAIB Aircraft Accident Report 1/2017.

Pilot's overall pattern of behaviour

The overall pattern of behaviour described by the analyses provided to the AAIB can be explained in other ways that do not require impairment as a common factor. The pitch oscillations, the pull-up technique and the decision not to eject were proposed as significant in some of the analyses but the AAIB did not consider them to be significant actions in the sequence. The pitch oscillations were assessed to be minor deviations probably due to the aircraft being slightly out of trim in pitch. The pull-up technique was consistent with the pilot's technique seen in other display videos. A decision to eject would not be taken in preference to flying an escape manoeuvre if the pilot realised this was required. By the time the situation was unrecoverable, the aircraft was outside the limits from which an ejection would be likely to be survivable.

The reduction in thrust[24] prior to the start of the loop, if commanded by the pilot[25], may have been an appropriate action if he intended to commence the loop at less than 350 kt, or if he mis-recalled the target speed. He may have considered the speed to be correct.

Any analysis of the pilot's position and pull-up point relies on assumptions about his plan. There was no evidence documenting the exact track he planned to fly and therefore none with which to compare the actual flight path. The track at the end of the positioning turn was only marginally different to what the pilot described when interviewed. Had he rolled out of the positioning turn earlier he would have flown over Lancing College; which was prohibited. On the actual final heading achieved, a later pull-up would have risked infringing the display line.

If the pilot had deviated from his planned positioning, he may have become preoccupied with this, causing him to pay less attention to flying the manoeuvre accurately. This could account for the early roll and perhaps the insufficient thrust.

For the pilot to decide to fly an escape manoeuvre he would need to: realise he was too low, believe that the escape manoeuvre was likely to be successful, and be capable of flying it. The RAFCAM human factors analysis considered the apex of the loop in depth.[26] It described several credible mechanisms by which the pilot could be unaware he was too low. For example, the AAIB investigation highlighted a design issue that would have increased the likelihood of misreading the altimeter due to the obscuration of the digit showing thousands of feet.[27] The investigation found that the pilot may not have known an escape manoeuvre could be successful from the height and speed achieved at the apex of the final manoeuvre. If the pilot realised he was too low, the time available may

Footnote

[24] Analysis of cockpit audio recordings from the accident flight enabled thrust levels to be assessed, but throttle movements were not visible in the cockpit image recordings. Section 1.11.3 on page 41 of Aircraft Accident Report 1/2017.

[25] An uncommanded reduction in thrust during the accident manoeuvre could not be ruled out. Finding 13 on page 196 of Aircraft Accident Report 1/2017

[26] See paragraphs 19 – 21, pages 415 - 418 of AAIB Aircraft Accident Report 1/2017.

[27] See Figure 28, page 129 of AAIB Aircraft Accident Report 1/2017.

only have been sufficient to execute a rule-based decision[28] of a practiced action. By the time it would have been obvious to the pilot he could not complete the loop safely it is unlikely it would have been possible to avoid the road.

Hence, the actions may have been linked together and do not require cognitive impairment as an explanation.

Whatever the explanations for the pilot's actions, air display flying is challenging. It is foreseeable that manoeuvres will sometimes differ from what was intended even with the most expert pilots and the best possible preparation. The AAIB investigation found that the severity of the outcome at Shoreham was due to the absence of provisions to mitigate the effects of an aircraft crashing in an area outside the control of the organisers of the flying display. Accordingly, the AAIB final report also explored the effectiveness of measures to protect the public from the hazards of displaying aircraft and made Safety Recommendations for improvement in this area.

Conclusion

The AAIB has reviewed the information provided and concluded that it does not constitute new and significant evidence.

This review has provided a more detailed understanding of the +Gz profile experienced by the pilot during the manoeuvres preceding the accident. It has also examined alternative analyses of the pilot's actions during the accident flight. The cockpit action camera footage from the accident flight and other displays by the pilot were reviewed again in light of the additional material provided. The AAIB found no new and significant evidence of cognitive impairment. There are credible alternative explanations for the pilot's actions which are supported by evidence presented in the AAIB final report and are considered more likely.

The findings of the AAIB investigation remain valid.

Footnote

[28] Rule based decision making can occur when there is a specific pre-determined action to take in response to a specific criterion or criteria. For example, IF the height at the apex of the loop is less than the minimum gate height THEN execute the escape manoeuvre. It requires the action and criteria to be known prior to having to make the decision.

APPENDIX 1 – Detailed estimates of Gz

The AAIB investigation found that the accident aircraft did not have a serviceable g-meter. Consequently, no direct indications of Gz were available. However, a study of the available data by the RAFCAM indicated the pilot would have experienced +Gz of 2.7 g in the positioning turn.

In this review the AAIB applied additional modelling techniques to provide more detailed estimates of Gz in the positioning turn and loop manoeuvre.

The AAIB final report provided speed[29] at the pull-up into the loop manoeuvre in terms of airspeed read from the right ASI and groundspeed from photogrammetry. It indicated these had the same values despite the presence of wind but did not explain why these were consistent. Given the relationship between airspeed and Gz, this appendix provides an explanation for the relationship between airspeed and groundspeed.

Gz during the positioning turn

The vertical (head to foot) force on a pilot normal to the flightpath is known as Gz. Gz generated during any turn, regardless of the aircraft type, is a factor of the shape of the three-dimensional (3-D) flightpath and the speed at which it is flown. The tighter the turn at a given speed the higher the Gz. Equally, for a given radius of turn, the faster it is flown the higher the Gz. Small flightpath changes also affect Gz by an amount proportional to the rate of these changes. Small changes in pitch, for example, generate momentary changes in Gz which either add to (when pitching up) or reduce (when pitching down) the Gz produced when flying the turn without these changes.

The 3-D flightpath and timing of the positioning turn can be used to calculate the Gz generated during the turn. Therefore, the accuracy of the calculated Gz depends on how well the flightpath of the aircraft can be determined.

Radar positions

The only direct location information available for the positioning turn are the radar returns from Pease Pottage and Gatwick radar[30] which have a degree of uncertainty. Horizontally this uncertainty is bounded by allowable system and random errors.[31]

The system errors for all radar heads in the UK are measured daily and so can be accounted for; however, the random errors will be different for every radar return and can only be taken into account by considering the allowable extent of these errors. The random errors for distance and bearing from the radar head are different, but for each radar return, a box can be drawn to represent with 95% confidence the range of possible positions of the target aircraft. Near to Shoreham the box would be 140 m long in the direction of the radar head,

Footnote

[29] See page 44 of AAIB Aircraft Accident Report 1/2017 which states that the pull-up at the start of this manoeuvre commenced at an indicated airspeed of 310 ±15 KIAS and groundspeed as 310 ±15 kt.

[30] See section 1.11.2 of AAIB Aircraft Accident Report 1/2017.

[31] EUROCONTROL Standard Document for Radar Surveillance in En-Route Airspace and Major Terminals SUR.ET1.ST01.1000-STD-01-01 March 1997.

and 75 m wide for Pease Pottage and 95 m wide for Gatwick (note that Gatwick is further away so the bearing swathe is slightly wider). The Mode C altitude data received by the radar stations[32] is in 100 ft increments and required to be within 125 ft (with 95% confidence) of the altimeter used on board the aircraft. Figure A-1 shows the radar returns of the aircraft for the flypast, positioning turn and loop, with the known system errors removed.

Position derived from photogrammetry

The radar data on its own does not define the flightpath sufficiently to rule out a wide variety of flightpaths transitioning through the radar boxes. However, the on-board imagery taken by the two action cameras mounted within the cockpit[33] showed a smooth path which provided assurance that any short-term variations in Gz were not large. This was also evident in the imagery of the aircraft taken from the ground. The same imagery can be further processed to more tightly define the flightpath. The action cameras show, for example, whether the flightpath was smooth or involved the aircraft pitching up and down, and which ground features the aircraft flew over.

When external references that support photogrammetry are present in the image, the position of the action cameras, and hence the aircraft, can be calculated along a 3-D flightpath. Both action cameras recorded at a rate of 25 frames per second, enabling the flightpath to be determined in more detail than using radar returns, which are spaced up to 6 seconds apart. Images from videos of the aircraft taken from the ground were also used to triangulate parts of the flightpath.

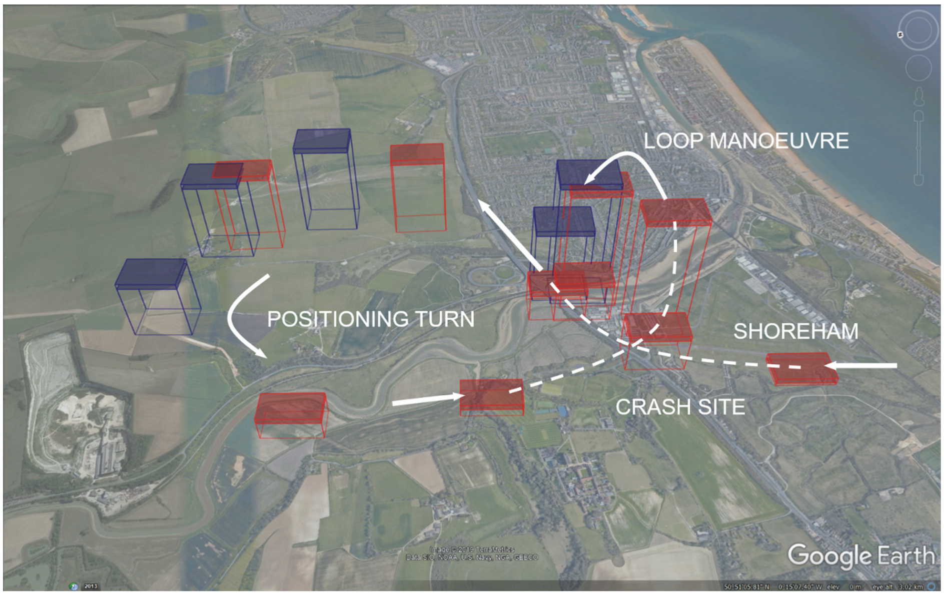

Figure A-1

Boxes showing with 95% confidence the position of the aircraft indicated by Pease Pottage (red) and Gatwick (blue) radar heads (note that the corners of the boxes have been extended down to show their position over the ground)

Footnote

32 Mode C is a type of secondary surveillance radar (SSR) system that requests identity and altitude information from the aircraft itself in additional to the measured position of the aircraft from detections.

33 See section 1.11.3 of AAIB Aircraft Accident Report 1/2017.

Assessment of how the positioning turn was flown

Extracts from both action cameras were analysed, starting just after the 270° roll of the Derry turn when the aircraft was just over 90° left-wing-down and climbing, ending 27 seconds later with the wings level just prior to pulling up for the loop. The turn was flown with only small perturbations in pitch and roll, consistent with the GoPro imagery of the right control column (which is connected directly to, and so, mirrors the pilot's control column) that shows no large amplitude movements of the control column.

Flightpath from photogrammetry

Photogrammetry, in which positional information is derived from photographs and videos, is well understood and used in an increasing number of software tools. It can be used, for example, to place a virtual object in a video sequence in which the camera position and perspective is constantly changing, or to generate models of urban environments from drone footage.

When necessary, the AAIB uses photogrammetry to generate 3D models of accident sites. By providing markers in the scene at known locations, the 3-D model can be scaled and positioned to allow measurements to be made as in the real world.

In video applications, photogrammetry software can analyse footage from a moving camera to create a 3-D model of what was filmed and can determine the position of the camera in the model for every video frame. The software can use actual locations of features appearing in the footage to reference these positions to the real world. With sufficient tracked features in the video, the software can model and compensate for camera lens distortions as part of the iterative process of refining the 3-D model of the surroundings and camera path.

It is possible to derive the position of an aircraft in a series of frames by applying this type of analysis to videos taken from within the aircraft and providing the geographical location of features in the video.

The use of the action camera videos to derive the location of the aircraft is only possible when known or derivable external references are in view. The GoPro video contained sufficient ground features to calculate the location of the camera from the end of the 270° roll of the Derry turn to when the aircraft rolled wings level for the start of the loop manoeuvre.

Figure A-2 shows a frame from the GoPro video and the associated track points used by the photogrammetry software. The position calculations close to the start of the pull-up of the loop manoeuvre are less accurate due to the diminishing view of ground reference points with the wings level. The cockpit windows create distortions in the imagery of the scene beyond it in a way that the software is not designed to derive and compensate for. However, the quality of the results indicates that the additional errors this introduces are small enough to be addressed adequately by a standard lens distortion derivation process.

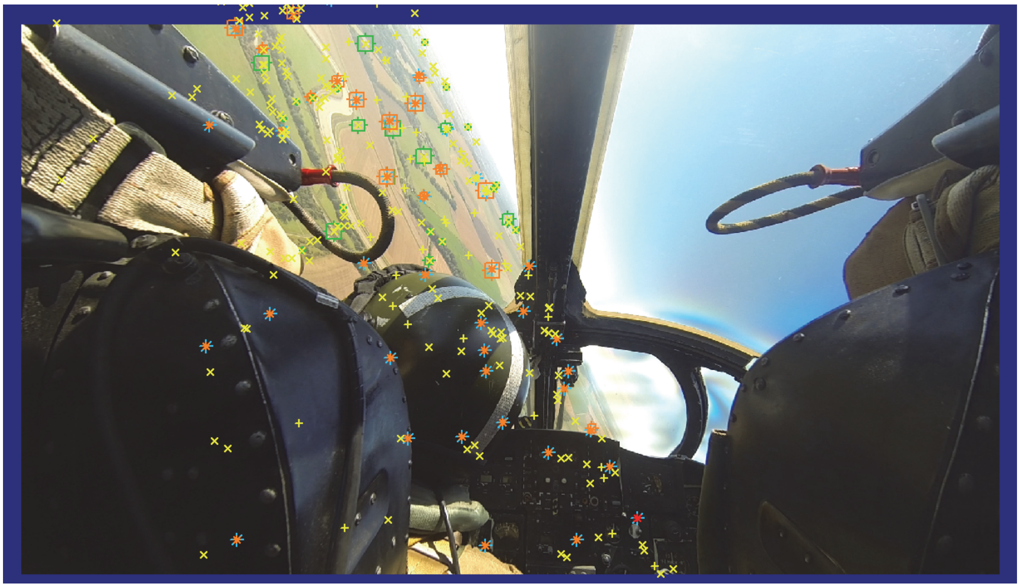

Figure A-2

Snapshot from the GoPro action camera with markers for track points and the locations of ground features including those not in frame or obscured in the frame

The DogCam video was roughly processed using fewer reference points to provide a reasonableness check of the GoPro results. This was done for a similar period to that of the GoPro analysis work to ensure the process was consistent using a different camera in the cockpit with a different view of the ground. The photogrammetry software declared more positional errors for the DogCam results, and these errors were apparent in the results. However, in general the calculated 3-D positions were consistent with the GoPro results (Figure A-3).

The GoPro video of the aircraft in the loop manoeuvre was also processed in order to compare the altitude this would generate with the other evidence associated with the loop apex altitude. This indicated an apex altitude within the band given in the AAIB final report, providing further evidence of the robustness of the process.

Some of the videos taken by the public from different locations captured both the aircraft and terrain in the background and so were suitable for photogrammetry. On their own they were used to generate the direction of the aircraft relative to the camera location. Used in pairs, they generated a triangulated flightpath. These were consistent with, and provided some additional flightpath information at the start of the loop, and correlated well with the paths derived from the on-board cameras.

Figure A-3

Overview and comparison of derived tracks from DogCam (dark pink dots) and GoPro (dark blue dots) cockpit action cameras with Pease Pottage (red) and Gatwick (blue) radar boxes

Figure A-4 compares the derived altitudes of the GoPro, DogCam and ground videos with each other and with the Mode C radar altitudes. They are consistent with each other and with the radar altitudes. Note that the along-track length of the radar boxes equates to a flight time of up to 2 seconds at a groundspeed of 300 kt. This is shown in Figure A-4 by the length of the horizontal lines through each of the points; the vertical lines represent the ±125 ft Mode C accuracy requirement. Note also that the radar altitudes were consistently between 50 and 200 ft less than the GNSS[34] recorded altitudes when the aircraft flew along the coast toward Shoreham.[35]

Footnote

[34] Global Navigation Satellite System.

[35] See section 1.11.6 of AAIB Aircraft Accident Report 1/2017.

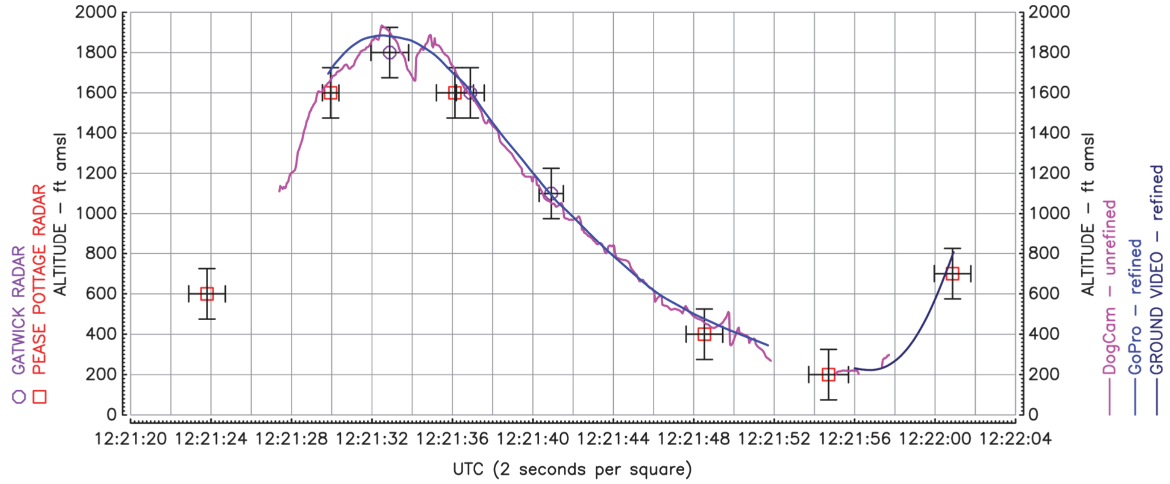

Figure A-4

Comparison of altitude derived from DogCam (dark pink), GoPro (dark blue) cockpit action cameras and ground video (black) with Pease Pottage (red square) and Gatwick (purple circle) Mode C altitudes

Gz calculations

Gz was calculated using a proprietary flight mechanics software tool. Assuming that the sideslip angle is small and the aircraft is not stalled, the equations of motion along a flightpath can be simplified such that the aircraft's orientation (heading, pitch and roll angles), velocities, Gz and other performance parameters can be determined as a function of time. The wind and atmospheric conditions must also be known[36] (because the wind affects the ground track), as well as the lift and drag characteristics of the aircraft[37] (to model angle of attack and thrust).

The flightpath analysis used two radar points (both from Pease Pottage) prior to the positioning turn, the first point being at the end of the flypast. This was to ensure that any errors at the start of the modelling, introduced by having to constrain the start point of the flightpath, were not part of the positioning turn. An interpolation routine was used to generate a continuous flightpath through these radar points and the set of video-derived positions during the turn and pull-up, interpolated at intervals of one second (a frequency of 1 Hz) for use in the flightpath analysis (Figures A-5 & A-6).

Footnote

[36] At 1220 hrs on the day of the accident, the Shoreham airport reported wind was 120° at 12 kt and the temperature was 24°C with a QNH of 1013 hPa (ie ISA+9).

[37] Ministry of Aviation Aeronautical Research Council R&M No. 3420 – *Flight Measurements of the Drag of a Swept-Wing Aircraft (Hunter Mk.1) at Mach Numbers up to 1.2, together with some Measurements of Lift-Curve Slope* – 1966. Note that the aerodynamic differences between the Hunter Mk.1 and Mk.7 are insignificant for the purposes of the flightpath analysis.

Figure A-5

1Hz interpolated flightpath ground track (light blue dots) through the radar boxes and the derived GoPro (dark blue dots) and ground video (black) positions

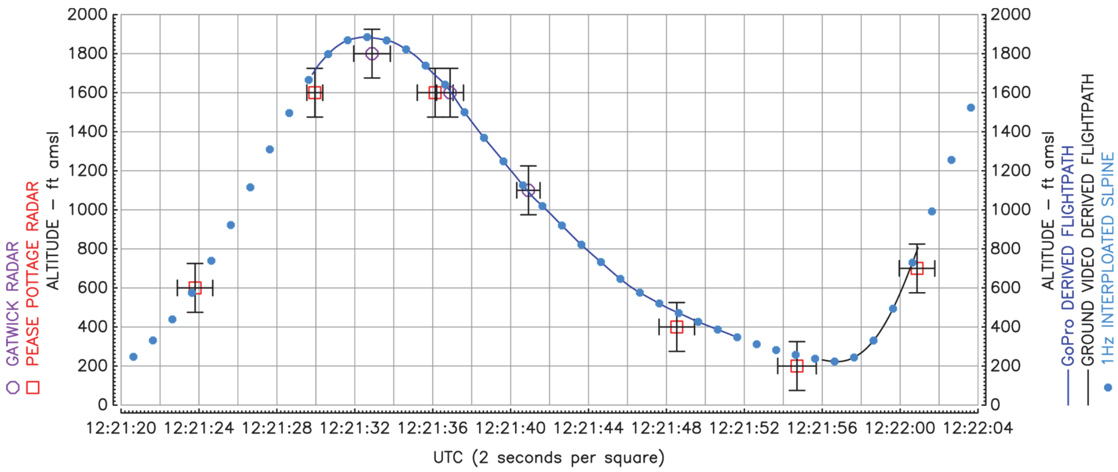

Figure A-6

1Hz interpolated altitude profile (light blue) through the radar boxes and the derivedGoPro (dark blue) and ground video (black) positions

Figure A-7 shows the results of the flightpath analysis. The top trace shows calculated +Gz during the positioning turn briefly at about 3.8 g (with the aircraft 90°+ left-wing-down) four seconds after the start of the positioning turn, when the turn rate peaked at about 12°/s. It then falls within three seconds to approximately 2.2 g, before rising slightly to a level predominantly around 3 g, then falling again to around 1 g over the final six seconds of the turn.

Note that the flightpath analysis did not roll the aircraft 270° right through the Derry turn flown by the aircraft prior to the positioning turn. Instead, it rolled the aircraft left through just over 90°. Consequently, the calculated Gz and airspeed during that period are unreliable.

The calculated bank angle is consistent with stills taken from the GoPro action camera, sampled every four seconds starting when the aircraft was in the 90°+ left-wing-down attitude. Similarly, the calculated airspeed[38] and the KIAS[39] trace taken from Figure 11 of the AAIB final report are consistent with each other, and only differ where the flightpath analysis has not modelled the 270° roll or where the photogrammetry has fewer points to track after the pull-up of the loop manoeuvre.

Sensitivity study

A sensitivity study looked at the effect on Gz of tightening and widening the turn radius by 100 m (corresponding approximately to the edges of the 95%-confidence horizontal boxes whilst maintaining a smooth turn). Figure 8 shows the results of this study. In summary, for the tighter turn the Gz levels reduced by about 0.4 g, and for the wider turn the Gz levels increased by about 0.4 g. The Gz for a tighter turn would be higher if flown at the same speed; however, because the length of the flightpath is reduced (by about 9%) but the time to fly it is the same (27 seconds), the speed is 36 kt lower. Similarly, for the wider turn, speed is 36 kt higher because of the increase in the length of the flightpath. Both these speeds exceed the ±15 kt error bounds of the right ASI readings by a factor of more than 2.

Therefore, the sensitivity analysis showed that, given the well-established bounds of the time taken to complete the manoeuvre, there would be little variation in Gz from the datum case due to any credible error in the turn radius.

Footnote

[38] The software calculates a calibrated airspeed (CAS) which has been corrected to indicated airspeed (IAS) by taking away 3 kt to account for the pressure error correction (PEC) for the Hawker Hunter for IASs between 280 and 380 kt (see section entitled *Indicated airspeed versus groundspeed at the start of the loop manoeuvre* of this appendix).

[39] Knots indicated airspeed

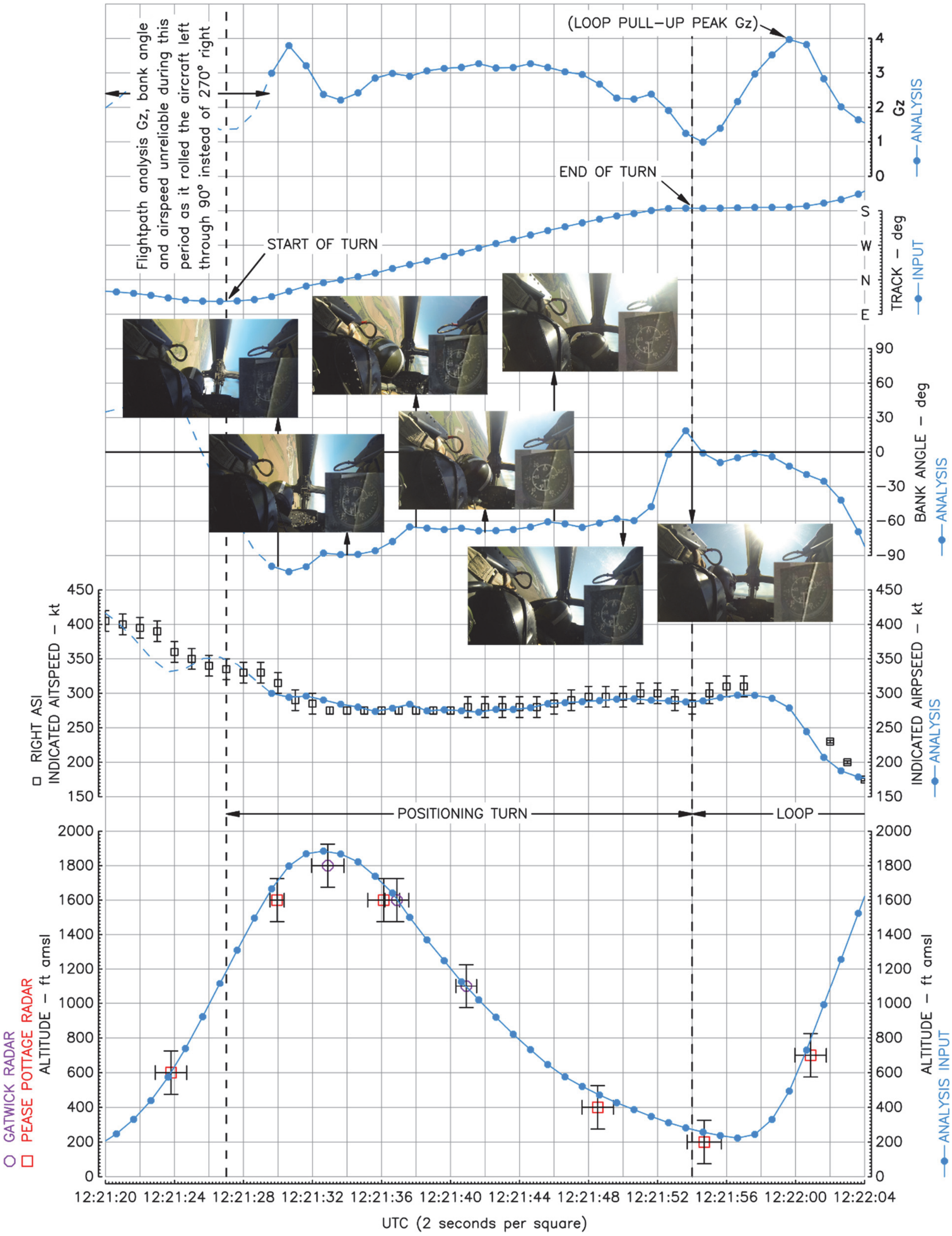

Figure A-7

Results of flightpath analysis to determine Gz in the positioning turn

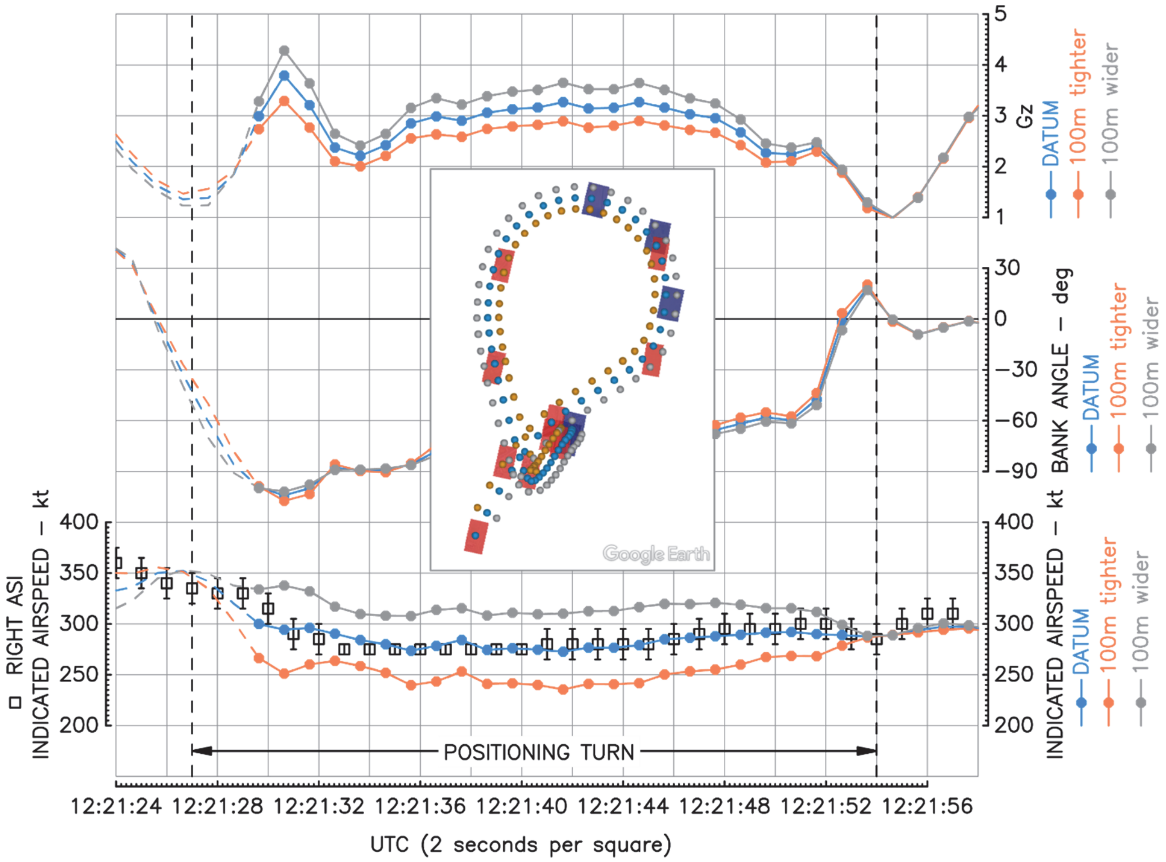

Figure A-8

Results of sensitivity study comparing datum flightpath analysis (light blue dots) with a turn which is tighter (orange dots) or wider (grey dots) by 100 m (the overlay shows a plan view of these tracks relative to the radar boxes)

Peak Gz during the loop manoeuvre

Maximum performance loops

During the data gathering flights described in Appendix H of the AAIB final report, 24 loops were flown at various speeds, thrusts and configurations: some straight, some bent. The minimum entry-to-apex height achieved was never less than 2,700 ft. Each of these loops were flown using the maximum performance of the aircraft[40] to minimise the radius of the loop and hence the height of the apex.

Footnote

[40] A maximum performance loop is defined as using the maximum available lift which is generated from flying with the maximum available angle of attack (α). Note that for a swept-wing aircraft, the C_L-α curve, which shows the relationship between lift (C_L) and α, flattens off at C_{Lmax} during which the buffet progressively grows from light to heavy as α is increased, before the wing stalls. Maximum α, therefore, can be achieved when the aircraft is in light buffet, with no gains in performance if buffet levels increase as the stick is pulled back further.

G profile of a maximum performance loop

Figure A-9 shows the Gz profile of a maximum performance loop that was flown during Sortie 3 of the data gathering flights. The Gz trace has lots of noise which is probably a result of the accelerometer used to measure the Gz vibrating; therefore, a smoothed moving average has been calculated to find the median Gz of the noise. The figure shows that the maximum Gz of 4.9 g occurred shortly after the initial pull-up, and since Gz is proportional to lift, which is proportional to equivalent airspeed[41] (EAS) squared, this corresponds to when the airspeed was at its highest. The G-onset rate peaked at 3.3 g/s.

The entry speed for the loop in Figure A-9 was 310 KIAS which was the highest entry speed for the loops flown in the flight trials. It was also the nominal entry speed for the accident manoeuvre.[42]

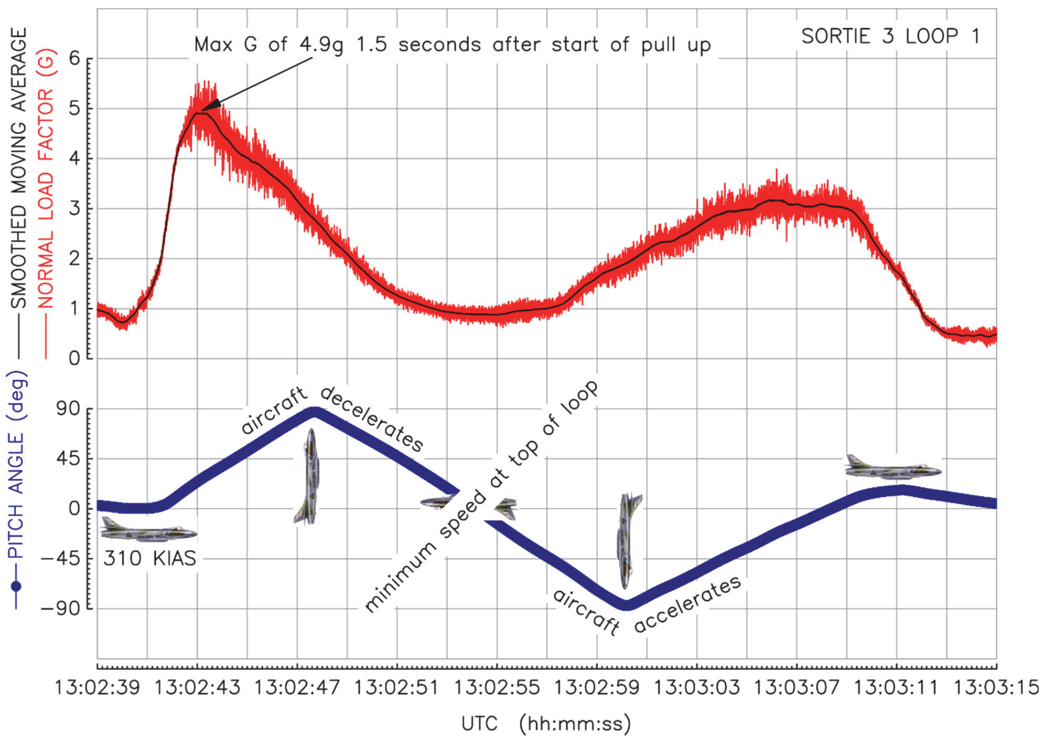

Figure A-9
Gz profile for a maximum performance (minimum radius) loop

Footnote

[41] The equivalent airspeed (EAS) is the airspeed at sea level in the International Standard Atmosphere (ISA) at which the dynamic pressure is the same as the dynamic pressure at the true airspeed (TAS) and altitude at which the aircraft is flying.

[42] Note that from the analysis in the previous section of this appendix, the airspeed at the end of the positioning turn with the wings level prior to pulling up for the loop manoeuvre was calculated to be about 290 KIAS; however, the aircraft was descending and accelerating at this point. As the stick was pulled back, and the aircraft's descent transitioned into the pull-up, the airspeed derived from the flightpath analysis peaked at just over 297 KIAS. This is consistent with the statement from the accident report.

Given that EAS = CAS = IAS + 3.5 kt,[43] the nominal 4.9 g corresponding to an entry speed of 310 KIAS can be factored to calculate the peak Gz had the entry speed been 310 - 15 = 295 KIAS or 310 + 15 = 325 KIAS. Therefore, for an entry speed of 295 KIAS, the peak Gz would have been:

$$+4.9 \times (295 + 3.5)^2 / (310 + 3.5)^2 = 4.4 \text{ g}$$

and for an entry speed of 325 KIAS, the peak Gz would have been:

$$+4.9 \times (325 + 3.5)^2 / (310 + 3.5)^2 = 5.4 \text{ g}$$

for a maximum performance loop.

Accident loop manoeuvre

The AAIB investigation concluded that during the accident loop manoeuvre the aircraft reached an altitude of 2,700 ±200 ft from an entry altitude of 225 ±25 ft. This means that the height gained from pull-up to apex was between 2,250 ft and 2,700 ft. The latter (2,700 ft) is consistent with the photogrammetry analysis which indicates an altitude of about 225 ft at entry and about 2,830 ft near the apex. The generated continuous flightpath through these points produces a calculated apex altitude of about 2,900 ft.

Figure A-10 shows the results of the flightpath analysis to determine the maximum Gz during the accident loop manoeuvre. It suggests a maximum Gz of 4 g which occurred about five seconds after the start of the manoeuvre. The G-onset rate peaked at 0.8 g/s with the Gz remaining above 3 g for about four seconds.

The speed was about 290 KIAS at the end of the positioning turn (with the aircraft still descending) and peaked at 297 KIAS two seconds later at the start of the climb.

Had this been a maximum performance loop, with an entry speed of 295 KIAS, the peak Gz would have been about 4.4 g; however, the lower G-onset of the accident manoeuvre indicates that the pull-up was not at maximum performance.

Photogrammetry provided a flightpath up to approximately 700 ft amsl, just beyond the point of peak G, after which the flight path model will be less accurate. This is evident in the divergence of the airspeeds later in the climb.

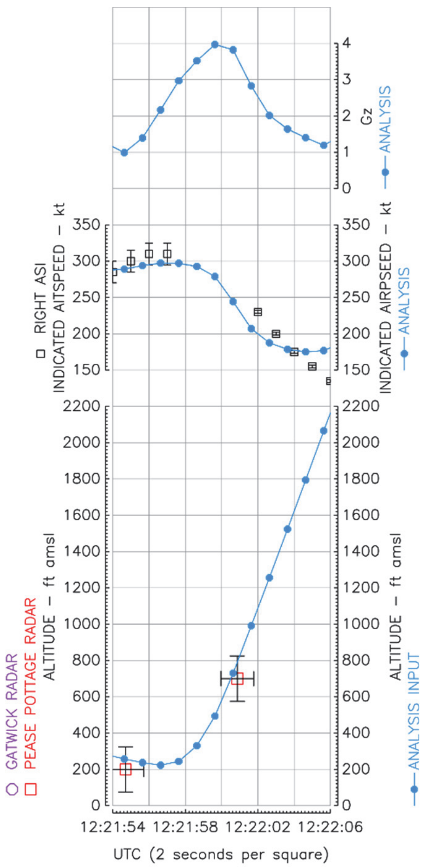

Figure A-10

Results of flightpath analysis to determine Gz during the loop pull-up

Footnote

43 See section entitled *Indicated airspeed versus groundspeed at the start of the loop manoeuvre* in this appendix.

Indicated airspeed versus groundspeed at the start of the loop manoeuvre

The following shows the relationship between indicated airspeed and groundspeed at the point of pull-up for the accident manoeuvre.

Relationship of true airspeed (TAS) with groundspeed (GS)

True airspeed is the speed of the aircraft relative to the airmass in which it is flying. If the airmass is moving over the ground at a certain speed (ie the wind speed), the relationship between true airspeed (TAS) and groundspeed (GS) is:

$$\text{TAS} = \text{GS} + \text{headwind component of the wind speed}$$

Given that the wind reported at Shoreham Airport at the time of the accident was 120° at 12 kt, and the heading of the aircraft was about 170°, the headwind component at the surface would have been 7.7 kt. However, because the manoeuvre started at about 225 ft, the headwind component would have been nearer 9 to 10 kt due to the wind gradient and veering of the wind with increasing altitude.[44] Therefore, at the start of the loop manoeuvre:

$$\text{TAS} = \text{GS} + 9.5\ \text{kt} \qquad (1)$$

Relationship between calibrated airspeed (CAS) and indicated airspeed (IAS)

Calibrated airspeed (CAS) is the indicated airspeed (IAS) corrected for instrument errors (which are not known for the aircraft) and position errors (in which the pressures sensed by the pitot-static system are not the actual free stream values). To correct for position errors, a position (or pressure) error correction (PEC) must be applied to the IAS to get CAS. Figure A11 shows the PECs for the Hawker Hunter Mk.7 in the configuration flown during the accident flight, indicating a PEC of +3.5 kt at about 300 KIAS.

Therefore, at the start of the loop manoeuvre:

$$\text{IAS} = \text{CAS} - 3.5\ \text{kt} \qquad (2)$$

Footnote

[44] Surface friction forces the surface wind to slow and change direction near the surface of the Earth when compared to the winds above the Earth's surface. The Met Office aftercast surface wind was approximately 10 kt increasing steadily with height to approximately 16 kt at 5,000 ft; therefore, at 225 ft the wind speed would have been no more than 1-2 kt more than the reported speed. In the northern hemisphere the wind direction veers (ie turns clockwise) with increasing altitude. A general rule of thumb is for the wind to veer by about 30° at 2,000 ft; therefore, a wind veer of 2-3° at 225 ft is not unreasonable.

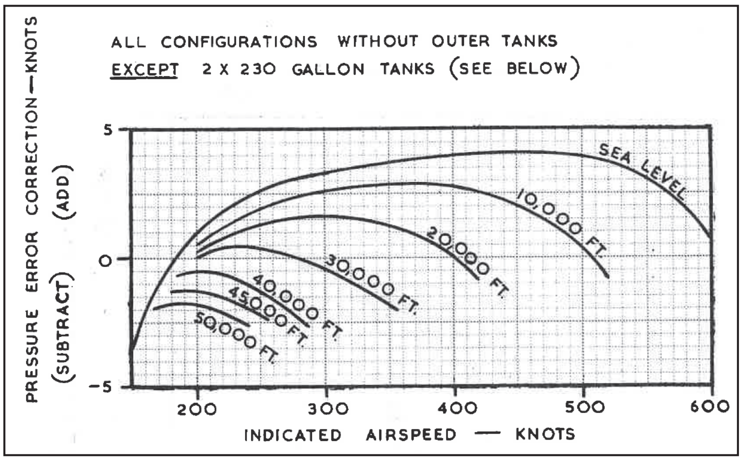

Figure A-11

PECs for Hawker Hunter Mk.7 for the configuration flown during accident flight

Relationship between CAS and TAS

It is also necessary to account for the effect of air density on the measurement of CAS. Air density is a function of altitude and temperature. The aircraft entered the manoeuvre at approximately 225 ft at an air temperature of 24°C (ISA + 9°C). Therefore, the relationship between CAS and TAS (and EAS) is given in the following table for calibrated airspeeds of 310±15 kt:

CAS – kt	TAS – kt	EAS – kt
295	301	295
310	316	310
325	331	325

Therefore, at the start of the loop manoeuvre:

$$\text{CAS} = \text{TAS} - 6 \text{ kt} \qquad (3)$$

Substitution between equations (1), (2) and (3) shows that:

$$\text{IAS} = \text{CAS} - 3.5 = (\text{TAS} - 6) - 3.5 = ((\text{GS} + 9.5) - 6) - 3.5 = \text{GS} \qquad (4)$$

This is consistent with the statement in the final report that both groundspeed and IAS were 310±15 kt.

Appendix 2 – Summaries of relevant literature referred to in submissions to the AAIB

Morrissette KL and McGowan DG (2000) Further Support for the Concept of a G-LOC Syndrome: A Survey of Military High-Performance Aviators. Aviation Space and Environmental Medicine, Vol 71, No 5, May 2000

The title of this paper refers to G-LOC but it is mostly concerned with A-LOC. It reports on the incidence of A-LOC episodes in military aviators and their memories of the symptoms they experienced.

The study used an anonymous survey of 329 military pilots and '*back seaters'*.[45] The survey was preceded by a verbal and video brief describing the mechanisms and symptoms of ALOC. The full questionnaire was not provided in the paper but appeared to include a pre-populated list of possible symptoms which participants could indicate if they had experienced. Of the 280 respondents 40 (14%) reported 1 or 2 episodes in which they had experienced various symptoms. The symptoms reported included sensory abnormality, motor abnormality, lack of recall and confusion. Of these, 58% were associated with loss of vision.

The paper was not considered significant evidence in relation to the G-BXFI accident for several reasons. The level of +Gz associated with symptoms was not captured or reported so it was not possible to assess if any of the episodes were at comparable exposure levels. It relied on flight crew memory of symptoms rather than any empirical measurement of the performance effects of these symptoms. The briefing prior to the questionnaire may have encouraged participants to report symptoms that they would not otherwise have mentioned.

In general, it is difficult to draw conclusions from self-report studies of the prevalence and symptoms of A-LOC because the symptoms described as A-LOC can also occur on recovery from G-LOC. G-LOC is associated with amnesia and a proportion of G-LOC events are not recalled. Therefore, it is not possible to determine if the respondents are accurately recalling A-LOC episodes. This applies equally to the following two studies by Rickards and Newman (2005) and Slungaard, McLeod, Green, Kiran, Newham and Harridge (2017).

Rickards CA; Newman DG (2005). G-Induced Visual and Cognitive Disturbances in a Survey of 65 Operational Fighter Pilots. Aviation Space and Environmental Medicine, Vol 76, No 5, May 2005

This study was another example of a pilot survey that collected self-reports of A-LOC events. The participants were fighter pilots then currently serving in the Royal Australian Air Force. The full survey was not available in the paper. It appeared to include a list of potential symptoms for the pilots to choose from. Of the 65 pilots who responded, 64 reported at least one episode of A-LOC symptoms or G-LOC and 34 pilots reported experiencing some

Footnote

[45] Occupants who were not in control of the aircraft.

of the following: abnormal sensation in limbs; disorientation; poor response to auditory stimuli; confusion and apathy.

The paper was not considered significant evidence in relation to the G-BXFI accident because it did not discuss the G exposure when the reported events occurred. Again, it relied on memory of symptoms rather than any empirical measurement of performance.

Slungaard E, McLeod J, Green NDC, Kiran A, Newham DJ, Harridge SDR (2017). Incidence of G Induced Loss of Consciousness and Almost Loss of Consciousness in the Royal Air Force. Aerospace Medicine and Human Performance, Vol 88, No 6, June 2017.

The aim of this survey was to measure the incidence of A-LOC and G-LOC episodes in pilots and weapons operators in the Royal Air Force. Of 809 aircrew who returned a survey, 120 (14.8%) reported one or more episodes of G-LOC and 260 (32.2%) reported one or more episodes of A-LOC. The participants were not asked about the specific symptoms they experienced. All the incidences of G-LOC or A-LOC were reported to have occurred when exposed to between +4 and +9 g. The majority occurred when exposed to between +5 and +5.9 g.

The study did not provide significant evidence in relation to the G-BXFI accident because it only covers incidence of A-LOC and G-LOC and not the effects of +Gz on pilot cognitive performance. It provided evidence that symptoms may be experienced at levels as low as +4 g. The paper did not state whether or not the pilots in these instances were wearing anti-g trousers. The finding of some symptoms at +4 g was consistent with the aeromedical information already available to the AAIB investigation so was not considered new and significant.

Shender BS, Forster EM, Hrebien L, Ryoo HC, Cammarota JP Jr (2003), Acceleration-induced near loss of consciousness: The "A-LOC" syndrome. Aviation Space and Environmental Medicine, Vol 74, No 10, October 2003.

This study was conducted in a human centrifuge. It included nine participants who were exposed to rapid onset pulses of +6, +8 and +10 g. The initial pulse in each set lasted 0.25 seconds and the duration of each subsequent pulse was increased in 1, 0.5 or 0.25 second increments, depending on participant response, until they lost consciousness. The participants were not protected with any anti-G clothing. The study collected a variety of data including: observation of the participants' physical symptoms; participants' experience of loss of vision; performance on a simple mathematical task; reported emotional state and the change in cerebral tissue oxygenation.

In total the study included 161 positive G pulses. A-LOC symptoms were observed or reported in 66 of these. The observable and reported effects of A-LOC included a variety of physical, cognitive, emotional and '*altered states of awareness*' symptoms. All participants who experienced A-LOC lost all vision (blackout) prior to the A-LOC episode. The cognitive symptoms documented were: confusion, amnesia, delayed recovery, difficulty forming words and disorientation. Participants gave an incorrect answer to the mathematical task

31 out of 66 times during the A-LOC episodes. There was a difference in cerebral tissue oxygenation in the 66 A-LOC events compared to the asymptomatic G pulses.

The results of this study were not considered relevant to the G-BXFI accident because the levels of +Gz exposure were much higher than those experienced by the accident pilot.

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GLOSSARY OF ABBREVIATIONS USED IN THIS SUPPLEMENT

3-D	three-dimensional
α	angle of attack
AAIB	Air Accidents Investigation Branch
A-LOC	almost loss of consciousness
amsl	above mean sea level
ASI	air speed indicator
CAS	calibrated airspeed
C_L	coefficient of lift
°C	Celsius
deg	degrees (angle)
EAS	equivalent airspeed
ft	feet
g	acceleration due to Earth gravity
G	acceleration due to aircraft manoeuvring
GNSS	Global Navigation Satellite System
GS	groundspeed
Gz	acceleration normal to the flight path (“head to foot”)
G-LOC	G induced loss of consciousness
hh	hours (in clock time, hh:mm:ss)
hPa	hectopascal (equivalent unit to millibar)
Hz	hertz
IAS	indicated airspeed
ISA	International Standard Atmosphere
KIAS	knots indicated airspeed
kt	knot(s)
m	metre(s)
mm	minutes (clock time)
PEC	pressure error correction
QNH	altimeter pressure setting to indicate elevation amsl
s	second(s)
ss	seconds (clock time)
TAS	true airspeed

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2/2014 Eurocopter EC225 LP Super Puma
G-REDW, 34 nm east of Aberdeen,
Scotland on 10 May 2012
and
G-CHCN, 32 nm south-west of
Sumburgh, Shetland Islands
on 22 October 2012.

Published June 2014.

3/2014 Agusta A109E, G-CRST
Near Vauxhall Bridge,
Central London
on 16 January 2013.

Published September 2014.

1/2015 Airbus A319-131, G-EUOE
London Heathrow Airport
on 24 May 2013.

Published July 2015.

2/2015 Boeing B787-8, ET-AOP
London Heathrow Airport
on 12 July 2013.

Published August 2015.

3/2015 Eurocopter (Deutschland)
EC135 T2+, G-SPAO
Glasgow City Centre, Scotland
on 29 November 2013.

Published October 2015.

1/2016 AS332 L2 Super Puma, G-WNSB
on approach to Sumburgh Airport
on 23 August 2013.

Published March 2016.

2/2016 Saab 2000, G-LGNO
approximately 7 nm east of
Sumburgh Airport, Shetland
on 15 December 2014.

Published September 2016.

1/2017 Hawker Hunter T7, G-BXFI
near Shoreham Airport
on 22 August 2015.

Published March 2017.

1/2018 Sikorsky S-92A, G-WNSR
West Franklin wellhead platform,
North Sea
on 28 December 2016.

Published March 2018.

2/2018 Boeing 737-86J, C-FWGH
Belfast International Airport
on 21 July 2017.

Published November 2018.

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GLOSSARY OF ABBREVIATIONS

aal	above airfield level
ACAS	Airborne Collision Avoidance System
ACARS	Automatic Communications And Reporting System
ADF	Automatic Direction Finding equipment
AFIS(O)	Aerodrome Flight Information Service (Officer)
agl	above ground level
AIC	Aeronautical Information Circular
amsl	above mean sea level
AOM	Aerodrome Operating Minima
APU	Auxiliary Power Unit
ASI	airspeed indicator
ATC(C)(O)	Air Traffic Control (Centre)(Officer)
ATIS	Automatic Terminal Information Service
ATPL	Airline Transport Pilot's Licence
BMAA	British Microlight Aircraft Association
BGA	British Gliding Association
BBAC	British Balloon and Airship Club
BHPA	British Hang Gliding & Paragliding Association
CAA	Civil Aviation Authority
CAVOK	Ceiling And Visibility OK (for VFR flight)
CAS	calibrated airspeed
cc	cubic centimetres
CG	Centre of Gravity
cm	centimetre(s)
CPL	Commercial Pilot's Licence
°C,F,M,T	Celsius, Fahrenheit, magnetic, true
CVR	Cockpit Voice Recorder
DFDR	Digital Flight Data Recorder
DME	Distance Measuring Equipment
EAS	equivalent airspeed
EASA	European Aviation Safety Agency
ECAM	Electronic Centralised Aircraft Monitoring
EGPWS	Enhanced GPWS
EGT	Exhaust Gas Temperature
EICAS	Engine Indication and Crew Alerting System
EPR	Engine Pressure Ratio
ETA	Estimated Time of Arrival
ETD	Estimated Time of Departure
FAA	Federal Aviation Administration (USA)
FIR	Flight Information Region
FL	Flight Level
ft	feet
ft/min	feet per minute
g	acceleration due to Earth's gravity
GPS	Global Positioning System
GPWS	Ground Proximity Warning System
hrs	hours (clock time as in 1200 hrs)
HP	high pressure
hPa	hectopascal (equivalent unit to mb)
IAS	indicated airspeed
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
IP	Intermediate Pressure
IR	Instrument Rating
ISA	International Standard Atmosphere
kg	kilogram(s)
KCAS	knots calibrated airspeed
KIAS	knots indicated airspeed
KTAS	knots true airspeed
km	kilometre(s)
kt	knot(s)
lb	pound(s)
LP	low pressure
LAA	Light Aircraft Association
LDA	Landing Distance Available
LPC	Licence Proficiency Check
m	metre(s)
mb	millibar(s)
MDA	Minimum Descent Altitude
METAR	a timed aerodrome meteorological report
min	minutes
mm	millimetre(s)
mph	miles per hour
MTWA	Maximum Total Weight Authorised
N	Newtons
N_R	Main rotor rotation speed (rotorcraft)
N_g	Gas generator rotation speed (rotorcraft)
N_1	engine fan or LP compressor speed
NDB	Non-Directional radio Beacon
nm	nautical mile(s)
NOTAM	Notice to Airmen
OAT	Outside Air Temperature
OPC	Operator Proficiency Check
PAPI	Precision Approach Path Indicator
PF	Pilot Flying
PIC	Pilot in Command
PM	Pilot Monitoring
POH	Pilot's Operating Handbook
PPL	Private Pilot's Licence
psi	pounds per square inch
QFE	altimeter pressure setting to indicate height above aerodrome
QNH	altimeter pressure setting to indicate elevation amsl
RA	Resolution Advisory
RFFS	Rescue and Fire Fighting Service
rpm	revolutions per minute
RTF	radiotelephony
RVR	Runway Visual Range
SAR	Search and Rescue
SB	Service Bulletin
SSR	Secondary Surveillance Radar
TA	Traffic Advisory
TAF	Terminal Aerodrome Forecast
TAS	true airspeed
TAWS	Terrain Awareness and Warning System
TCAS	Traffic Collision Avoidance System
TODA	Takeoff Distance Available
UA	Unmanned Aircraft
UAS	Unmanned Aircraft System
USG	US gallons
UTC	Co-ordinated Universal Time (GMT)
V	Volt(s)
V_1	Takeoff decision speed
V_2	Takeoff safety speed
V_R	Rotation speed
V_{REF}	Reference airspeed (approach)
V_{NE}	Never Exceed airspeed
VASI	Visual Approach Slope Indicator
VFR	Visual Flight Rules
VHF	Very High Frequency
VMC	Visual Meteorological Conditions
VOR	VHF Omnidirectional radio Range

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