AIRCRAFT ACCIDENT REPORT 1/2017

AAIB
Air Accidents Investigation Branch

Report on the accident to
Hawker Hunter T7, G-BXFI
near Shoreham Airport
on 22 August 2015

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This report contains facts which have been determined up to the time of publication. This information is published to inform the aviation industry and the public of the general circumstances of accidents and serious incidents.

Published 3 March 2017

Printed in the United Kingdom for the Air Accidents Investigation Branch

Department for Transport
Air Accidents Investigation Branch
Farnborough House
Berkshire Copse Road
Aldershot
Hampshire GU11 2HH

February 2017

The Right Honourable Chris Grayling
Secretary of State for Transport

Dear Secretary of State

I have the honour to submit the report on the circumstances of the accident to Hawker Hunter T7, registration G-BXFI near Shoreham Airport on 22 August 2015.

Yours sincerely

Crispin Orr
Chief Inspector of Air Accidents

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Contents

Appendices

GLOSSARY OF ABBREVIATIONS USED IN THIS REPORT

°C	Degrees Centigrade
°M	Degrees Magnetic
AAIB	Air Accidents Investigation Branch
aal	above aerodrome level
AAN	Airworthiness Approval Note
ACAM	Aircraft Continuing Airworthiness Monitoring
ACU	Acceleration Control Unit
AEA	Aircrew equipment assemblies
agl	above ground level
AIP	Aeronautical Information Publication
ALARP	As low as reasonably practicable
AME	Aviation Medical Examiner
AMOC	Alternative Means of Compliance
amsl	above mean sea level
ANO	Air Navigation Order
ASI	Airspeed Indicator
ATC	Air Traffic Control
ATCO	Air Traffic Controller
ATRE	Approved Type Rating Exemption
BADA	British Air Display Association
BCAR	British Civil Airworthiness Requirement
BKN	Broken cloud
BPC	Barometric Pressure Control
BTRU	Barostatic Time Release Unit
BVCU	Bleed Valve Control Unit
CAA	Civil Aviation Authority
CAMO	Continuing Airworthiness Management Organisation
CAP	Civil Aviation Publication
CAVOK	Ceiling And Visibility OK (for VFR flight)
CT	Computer tomography
DA	Display Authorisation
DAE	Display Authorisation Evaluator
EASA	European Aviation Safety Agency
EEPA	Emergency escape parachute assembly
EKQ	Essential knowledge quiz
ESG	Emergency Services Group
FAA	Federal Aviation Administration
FACTOR	Follow-up Action on Occurrence Report
FCC	Flying Control Committee
FCU	Fuel Control Unit
FDD	Flying Display Director
FHT	Final Handling Test
FSO	Flight Standards Officer
GA	General aviation
GAU	General Aviation Unit
GBASF	General Business and Aviation Strategy Forum
GNSS	Global Navigation Satellite System
HF	Human factors
hp	horse power
HPSOV	High pressure fuel shut-off valve
HSE	Health and Safety Executive
HSL	Health and Safety Laboratory
IAS	Indicated airspeed
ICAO	International Civil Aviation Organisation
ICAS	International Council of Air Shows
JPT	Jetpipe temperature
kg	Kilogram
KIAS	Indicated airspeed in kt
km	Kilometre
kt	knot
m	metre
MAA	Military Aviation Authority
MEP	Multi-engine piston
MOD	Ministry of Defence
MPAUM	Maximum permitted all-up mass
MPD	Mandatory Permit Directive

GLOSSARY OF ABBREVIATIONS USED IN THIS REPORT

nm	nautical mile
NPF	National Permit to Fly
OCM	Organisational Control Manual
OEM	Original Equipment Manufacturer
OVC	Overcast cloud
PFL	Practice Forced Landing
PSP	Personal survival pack
QFE	altimeter pressure setting to indicate height above aerodrome
QFI	Qualified Flying Instructor
QMS	Quality Management System
QNH	altimeter pressure setting to indicate elevation amsl
QRF	Quick release fitting
RAF	Royal Air Force
RAFA	Royal Air Force Association
RAFCAM	Royal Air Force Centre of Aviation Medicine
RSMS	Regulatory Safety Management System
SB	Special Bulletin
SEP	Single-engine piston
SERA	Standardised European Rules of the Air
SMS	Safety Management System
SOAP	Spectrographic Oil Analysis Programme
SPFH	Seat Pan Firing Handle
SSP	State Safety Programme
STAMP	Systems Theory Accident Modelling and Process
TP	Test Pilot
UAV	Unmanned aerial vehicle
UTC	Co-ordinated Universal Time (GMT)
VFR	Visual Flight Rules

Air Accidents Investigation Branch

Aircraft Accident Report No: 1/2017

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)

Introduction

The accident was reported to the Air Accidents Investigation Branch by Shoreham Air Traffic Control.

In exercise of his powers, the Chief Inspector of Air Accidents ordered an investigation to be carried out in accordance with the Civil Aviation (Investigation of Air Accidents and Incidents) Regulations 1996 and the European Regulations EU996/2010 on the investigation and prevention of accidents and incidents in civil aviation. The sole objective of the investigation under these Regulations is the prevention of accidents and incidents and not the apportioning of blame or liability.

The AAIB dispatched a team of investigators and support staff to the accident scene to commence an investigation immediately.

1 Coordinated Universal Time.

Summary

At 1222 UTC (1322 BST) on 22 August 2015, Hawker Hunter G-BXFI crashed on to the A27, Shoreham Bypass, while performing at the Shoreham Airshow, fatally injuring eleven road users and bystanders. A further 13 people, including the pilot, sustained other injuries.

The AAIB investigation considered the circumstances in which the aircraft came to be in a position from which it was not possible to complete its intended manoeuvre, and the reasons for the severity of the outcome.

The AAIB recognises that as well as being enjoyed by large numbers of spectators and participants, flying displays are also considered to provide important economic and educational benefits[2].

A safe flying display relies on the training and experience of the participating pilots, the airworthiness of the aircraft, and the planning and risk management of the event. Regulations, guidance and oversight provide the framework for these activities.

The aircraft was carrying out a manoeuvre involving both a pitching and rolling component, which commenced from a height lower than the pilot's authorised minimum for aerobatics, at an airspeed below his stated minimum, and proceeded with less than maximum thrust. This resulted in the aircraft achieving a height at the top of the manoeuvre less than the minimum required to complete it safely, at a speed that was slower than normal.

Although it was possible to abort the manoeuvre safely at this point, it appeared the pilot did not recognise that the aircraft was too low to complete the downward half of the manoeuvre. An analysis of human performance identified several credible explanations for this, including: not reading the altimeter due to workload, distraction or visual limitations such as contrast or glare; misreading the altimeter due to its presentation of height information; or incorrectly recalling the minimum height required at the apex.

The investigation found that the guidance concerning the minimum height at which aerobatic manoeuvres may be commenced is not applied consistently and may be unclear.

There was evidence that other pilots do not always check or perceive correctly that the required height has been achieved at the apex of manoeuvres.

Training and assessment procedures in place at the time of the accident did not prepare the pilot fully for the conduct of relevant escape manoeuvres in the Hunter.

Footnote

[2] Response of the Royal Aeronautical Society to the CAA air display charges consultation, 29 February 2016.

The manoeuvre was continued and the aircraft struck the ground on the northern side of the westbound carriageway of the A27 close to the central reservation with a ground track at a slight angle to the direction of the road. When it struck the ground it broke into four main sections. Fuel and fuel vapour released from the fuel tanks ignited. In its path were vehicles that were stationary at, or in the vicinity of, the traffic lights at the junction with the Old Shoreham Road, and pedestrians standing by the junction.

The pilot did not attempt to jettison the aircraft's canopy or activate his ejection seat. However, disruption of the aircraft due to the impact activated the canopy jettison process and caused the ejection seat firing mechanism to initiate. The seat firing sequence was not completed due to damage sustained by its firing mechanism during the impact. The seat was released from the aircraft and the pilot was released from the seat as a result of partial operation of the sequencing mechanism. Some of the pyrotechnic cartridges remained live and were a hazard to first responders until they were made safe.

The investigation found that the aircraft appeared to be operating normally and responding to pilot control inputs until it impacted the ground. Defects in the altimeter system would have resulted in the height indicated to the pilot being lower than the actual aircraft height at the apex of the manoeuvre.

Information included in a previous AAIB report indicated that there had been several cases involving the type of engine fitted to this aircraft where an un-commanded reduction in engine speed had occurred and subsequent engineering investigation did not establish a clear cause. This investigation was unable to determine whether a reduction in engine speed recorded during the accident manoeuvre was commanded by the pilot.

The aircraft's engine was subject to a Mandatory Permit Directive (MPD) which imposed a calendar life on the engine type, and provided an option to extend that life using an Alternative Means of Compliance (AMOC). Proposals for an engine life extension using an AMOC inspection programme had to be approved by the regulator. Related tasks were being conducted by the maintenance organisation, but the regulator had not approved the operator or its maintenance organisation to use an AMOC to this MPD.

The investigation found that defects and exceedences of the aircraft's operational limits had not been reported to the maintenance organisation, and mandatory requirements of its Airworthiness Approval Note had not been met. During prolonged periods of inactivity the aircraft's engine had not been preserved in accordance with the approved maintenance schedule. The investigation identified a degraded diaphragm in the engine fuel control system, which could no longer be considered airworthy. However, the engine manufacturer concluded it would not have affected the normal operation of the engine.

The aircraft had been issued with a Permit to Fly and its Certificate of Validity was in date, but the issues identified in this investigation indicated that the aircraft was no longer in compliance with the requirements of its Permit to Fly.

The investigation found that the parties involved in the planning, conduct and regulatory oversight of the flying display did not have formal safety management systems in place to identify and manage the hazards and risks. There was a lack of clarity about who owned which risk and who was responsible for the safety of the flying display, the aircraft, and the public outside the display site who were not under the control of the show organisers.

The regulator believed the organisers of flying displays owned the risk. Conversely, the organiser believed that the regulator would not have issued a Permission for the display if it had not been satisfied with the safety of the event. The aircraft operator's pilots believed the organiser had gained approval for overflight of congested areas, which was otherwise prohibited for that aircraft, and the display organiser believed that it was the responsibility of the operator or the pilot to fly the aircraft's display in a manner appropriate to the constraints of the display site.

No organisation or individual considered all the hazards associated with the aircraft's display, what could go wrong, who might be affected and what could be done to mitigate the risks to a level that was both tolerable and as low as reasonably practicable.

Controls intended to protect the public from the hazards of displaying aircraft were ineffective.

The investigation identified the following causal factors in the accident:

- The aircraft did not achieve sufficient height at the apex of the accident manoeuvre to complete it before impacting the ground because the combination of low entry speed and low engine thrust in the upward half of the manoeuvre was insufficient.

- An escape manoeuvre was not carried out, despite the aircraft not achieving the required minimum apex height.

The following contributory factors were identified:

- The pilot either did not perceive that an escape manoeuvre was necessary, or did not realise that one was possible at the speed achieved at the apex of the manoeuvre.

- The pilot had not received formal training to escape from the accident manoeuvre in a Hunter and had not had his competence to do so assessed.

- The pilot had not practised the technique for escaping from the accident manoeuvre in a Hunter, and did not know the minimum speed from which an escape manoeuvre could be carried out successfully.

- A change of ground track during the manoeuvre positioned the aircraft further east than planned producing an exit track along the A27 dual carriageway.

- The manoeuvre took place above an area occupied by the public over which the organisers of the flying display had no control.

- The severity of the outcome 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.

The AAIB has published three Special Bulletins (SB) highlighting areas of concern that required timely consideration.

SB 3/2015, published on 4 September 2015, 13 days after the accident, reported initial information about the occurrence.

SB 4/2015, published on 21 December 2015, dealt with the safety of first responders to the accident scene, the maintenance of ejection seats in historic ex-military aircraft and issues regarding the maintenance of ex-military aircraft on the UK civil register. Seven Safety Recommendations were made.

SB 1/2016, published on 10 March 2016, considered the risk management of flying displays, minimum display heights and separation distances, regulatory oversight and piloting standards. It contained a further 14 Safety Recommendations, and was published to inform the air display community ahead of the 2016 air display season.

A further 11 Safety Recommendations are made in this report.

1 Factual Information

1.1 History of the flight

1.1.1 Background

The pilot was interviewed on seven separate occasions by the AAIB after the accident. Because of his injuries, these interviews were conducted in accordance with restrictions advised by his doctors. In order to comply with these restrictions the AAIB was not able to question the pilot on his conduct of the accident flight. He did not recall events between the evening of Wednesday 19 August 2015 and regaining consciousness in hospital after the accident. Consequently, although he was able to describe his normal practice, he was not able to describe events on the day of the accident.

The aircraft was fitted with two image recording devices ('action cameras') in the cockpit. These provided a significant amount of information about the accident flight. Recordings of other flying displays flown by the same pilot were also analysed, including manoeuvres similar to the accident manoeuvre.

1.1.2 The display – general preparation

The pilot stated that normally he prepared the evening before a display by reading his ground-school notes which described the operation of the aircraft and the limitations to be observed. He would liaise with the engineering staff at the aircraft's North Weald base to have it checked and refuelled as he required, and provide timings to ensure everything was ready in good time.

Daily engineering checks would be carried out and signed by the maintenance engineers. The pilot carried out his own pre-flight inspection and cockpit preparation. After he strapped in, all the ejection seat safety pins would be removed before engine start.

The pilot planned a sequence of aerobatic manoeuvres which could be modified for local considerations such as weather. An annotated map showing his intended sequence of manoeuvres was found in his pocket after the accident (see Figure 17). He described one of the manoeuvres he planned for the Shoreham Airshow as a 'bent loop' (see Section 1.18.1). This would be preceded by a flypast and Derry Turn, with the aircraft positioning in a left turn back towards the crowd line. His display in the Hunter at Shoreham in 2014 commenced with similar manoeuvres, during which he extended the left turn to go west around Lancing College. From that position it was necessary to bend the loop more than he wished, so in 2015 he planned to turn between the aerodrome and the College.

The aircraft's airspeed at entry to the 'bent loop' was to be a minimum of 350 KIAS, and if the airspeed was less than this the manoeuvre would not be attempted. If the airspeed was at least 350 KIAS, the nose would be pitched up and maximum thrust set. Approaching the vertical in the subsequent climb, the aircraft would be rolled to the left to arrive at the apex inverted with an airspeed of about 150 KIAS. The pitch rate would be judged during the climb to ensure that a minimum 'gate' height of 4,000 ft was achieved at the apex. This gate height was the sum of 3,000 ft, needed to carry out the downward half of the loop, his minimum authorised height of 500 ft for conducting aerobatics in a Hunter, and an additional 500 ft as a safety margin. The pull-through from the apex would allow the aircraft to accelerate, the heading to be controlled to obtain the correct track for the next manoeuvre, and the pitch rate to be adjusted to achieve the required height.

1.1.3 The accident flight

On the day of the accident the pilot was scheduled to carry out his sequence of aerobatic manoeuvres in the Hawker Hunter aircraft at the Royal Air Force Association (RAFA) Airshow at Shoreham Airport in Sussex. He had flown his light aircraft to North Weald Airfield in Essex where the Hunter was based. The daily inspection had been carried out the previous afternoon by an engineer and the pilot carried out a pre-flight inspection on the day. He requested that the aircraft was fully fuelled and this was carried out by the two ground crew. The pilot was described as being in good spirits and looking forward to the flight.

With preparations complete, the pilot seated himself in the left seat and secured his harness before donning his helmet. The ground crew noticed that all the ejection seat and system safety pins had been removed from their safety positions, making the seats and system 'live', and were in their dedicated stowage. The engine start appeared normal and the pilot decided to take off from Runway 02, which had a downslope and a tailwind. After taxiing along Runway 12, the aircraft backtracked Runway 02 and lined up for departure.

The weather was good. The nearest official weather station, at Stansted, recorded a surface wind from 150° at 14 kt, no cloud below 5,000 ft, visibility more than 10 km, temperature 28°C, dewpoint 16° C and QNH[1] 1014 hPa.

The aircraft departed at 1204 hrs. The takeoff run was longer than usual due to the high air temperature and tailwind, and the pilot raised the nose of the aircraft to begin the lift-off at 112 KIAS instead of the 120 KIAS he would use normally. Once airborne, the aircraft flew towards the south coast east of Shoreham.

1 QNH is the reference barometric pressure set on an altimeter in order to display height above mean sea level, or altitude.

The flight south was uneventful and the aircraft carried out a left-hand orbit over the sea near Brighton between 1,800 ft and 2,500 ft. The pilot was then cleared to commence his display and, remaining offshore, flew west along the coast towards Shoreham Airport. At 1220 hrs Shoreham Airport reported wind from 120° at 12 kt, with no significant cloud and visibility of more than 10 km. The temperature was 24° C, dewpoint 17° C and QNH 1013 hPa. The pilot flew parallel to the coast in a gradual descent during which he flew inverted briefly, probably to check that there were no loose articles in the cockpit before his display.

Having rolled upright and wings level, the aircraft descended to 800 ft and made a right turn to line up with the display line to the west of Runway 02/20 at Shoreham. The aircraft remained right wing low with the angle of bank decreasing as it descended to 100 ft and flew along the display line. It then commenced a gentle climbing right turn, executed a Derry Turn (Figure 1) to the left which peaked at 1,800 ft, then entered a descending left turn to approximately 185 ft agl, approaching the display line at an angle of about 25º.

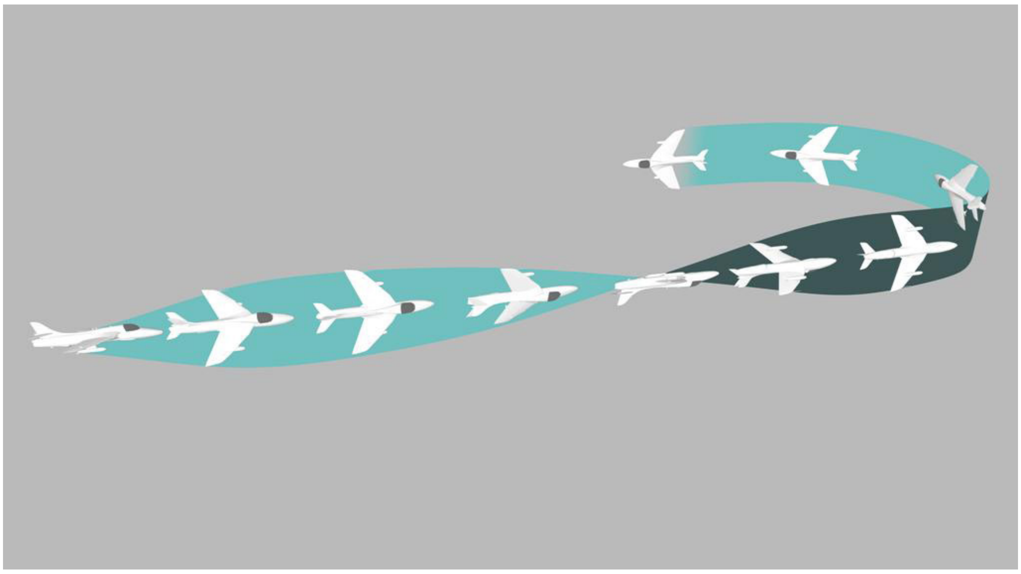

Figure 1

An illustration of a flat Derry Turn

With the aircraft in a right turn, the pilot stops the pitch rate, rolls the aircraft to the right through the inverted, stops the roll at the required bank angle and pulls into a turn to the left.

The aircraft then pitched up into the accident manoeuvre at an indicated airspeed of approximately 310 KIAS and with an engine speed of approximately 7,500 rpm[2]. As it approached the vertical, the pilot initiated a roll to the left. In the climb the engine speed first reduced, then increased to about 7,200 rpm, then reduced again nearing the apex. The aircraft was almost inverted with its wings level at the apex, at a height of approximately 2,700 ft. During the subsequent descent, its ground track was aligned to the west along the A27, Shoreham Bypass. As it descended it accelerated and the nose was raised but insufficient height was available to recover to level flight before it contacted the westbound carriageway of the A27.

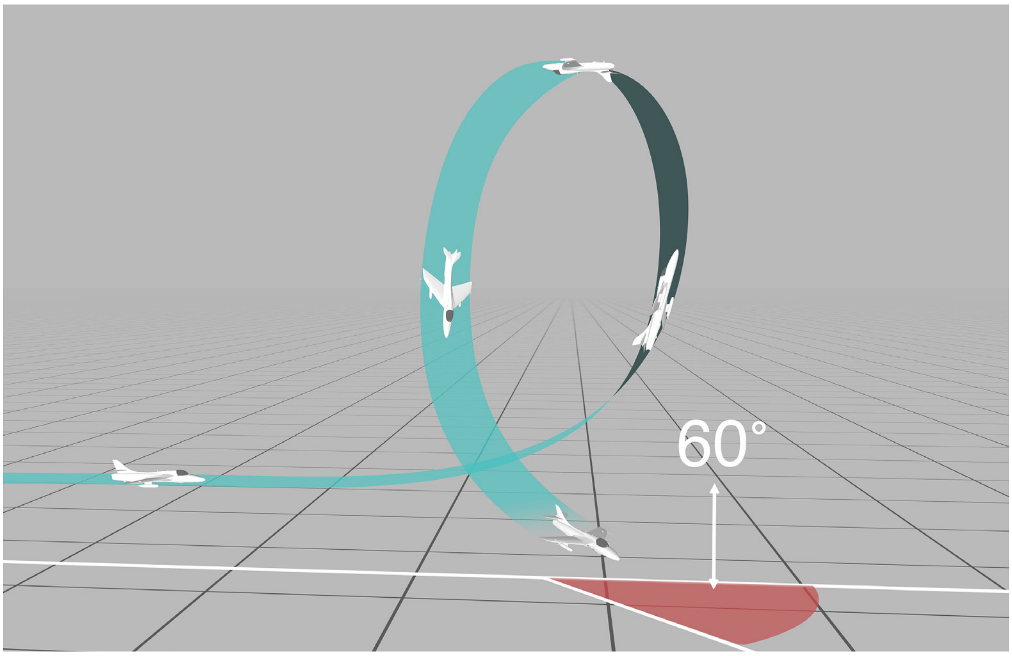

Figure 2

Illustration of the accident manoeuvre
(This is not a precise depiction of the aircraft's behaviour or flightpath)

Action camera recordings appeared to show that throughout the flight the pilot was conscious and that the aircraft was responding to his control inputs. Engine instruments that were visible did not indicate any engine malfunctions.

2 The maximum permitted engine speed is 8,100±50 rpm.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	-	-	11
Serious*	1	-	1
Minor	-	-	11

* ICAO Annex 13 and Regulation (EU) 996/2010 define a 'serious injury' as:

An injury which is sustained by a person in an accident and which:

a) requires hospitalization for more than 48 hours, commencing within seven days from the date the injury was received; or
b) results in a fracture of any bone (except simple fractures of fingers, toes or nose); or
c) involves lacerations which cause severe haemorrhage, nerve, muscle or tendon damage; or
d) involves injury to any internal organ; or
e) involves second or third degree burns, or any burns affecting more than 5 per cent of the body surface; or
f) involves verified exposure to infectious substances or injurious radiation.

1.3 Damage to the aircraft

The aircraft was destroyed.

1.4 Other damage

The aircraft crashed on the A27, Shoreham Bypass and impacted a number of occupied vehicles, pedestrians, street furniture, and vegetation on the roadside verge. The road surface and surrounding vegetation were affected by fire, heat and the effects of fuel. A pool of fuel and oil was present on the ground by the main wreckage.

1.5 Personnel information

1.5.1 Commander

Age:	51 years
Licence:	Airline Transport Pilot's Licence / Private Pilot's Licence
Aircraft Rating:	Aircraft Type Rating Exemption[3] valid to 27 August 2015
Medical Certificate:	Class 1 medical certificate valid to 31 January 2016
Display Authorisation:	Valid to 24 July 2016
Two-yearly check:	Valid to 23 March 2016
Flying experience:	Total hours - 14,249 hours
	On type - 43 hours
	Last 90 days - 115 hours
	Last 28 days - 53 hours

1.5.1.1 Career history

Military flying

The pilot joined the Royal Air Force (RAF) in 1985 and flew Jet Provost, Hawk and Harrier jet aircraft. He was a Qualified Flying Instructor (QFI) on the Jet Provost between 1988 and 1990.

In his RAF Pilot's Log Book, he had recorded his total flying time in military jet aircraft as:

Jet Provost MK 3A/5A	-	934 hours
Hawk MK1/1A	-	188 hours
Harrier T4/GR3, GR5/7	-	517 hours

Civil flying

The pilot left the RAF in 1994 having obtained a UK Civil Aviation Authority (CAA) Flying Instructor rating. He instructed on a range of single-engine piston aeroplanes before joining an airline to operate commercial jet transport aircraft which he continued to fly up to the time of the accident.

In 2003 he began flying a Jet Provost ex-military training aircraft in the civilian environment, operating from its base at North Weald. He completing one or two familiarisation flights and a check flight with the operator's Chief Pilot. Later he began instructing civilian pilots on Jet Provost aircraft.

3 See Section 1.5.1.3, below Table 1.

In 2005 he bought a self-build RV-8 aircraft, which he completed in the autumn of 2007. He used it extensively for recreational purposes and also to fly between his home and North Weald for Jet Provost training. In 2008 he commenced display flying in an RV-8 single-engine piston aircraft. He carried out some formation aerobatics with an experienced display pilot and obtained his first display authorisation (DA) in October 2008, valid for intermediate solo aerobatics and as a formation member. The formation was normally led by another pilot and a sequence of manoeuvres was trained and practised. He was also a formation instructor with another organisation at North Weald, and had set up a formation flying school using various RV aircraft.

1.5.1.2 Use of speed and height 'safety gates' in military flying

The pilot began training for aerobatic display flying with the RAF in 1989 when he was a QFI on the Jet Provost. He described the 'safety gates' he used when flying the Jet Provost aircraft as follows:

'When flying aerobatic manoeuvres in the Jet Provost the safety gate was a height and airspeed. In certain manoeuvres, such as a barrel roll, this was critical. The loop was less so because the safety gate height was below the minimum height achievable after a normal 'pull up'. With the barrel roll, the entry airspeed was the first safety gate followed by the nose attitude after rolling 180 degrees. The nose must not be below the horizon and a certain height and airspeed otherwise an unusual position recovery would have to be flown. Generally there was not a safety gate at altitude, but there was at the lower levels used for display flying. For a loop at a lower level, the minimum entry speed was 220 knots and the apex height for the pull through was 2,200 feet plus the height above the surface by which the manoeuvre had to be completed.'

'If the aircraft did not achieve the safety gate, it was effectively in an unusual position and a recovery manoeuvre must be flown. Three classic types of unusual position recovery were taught in the Jet Provost in the RAF, these were:

1. *With a nose high attitude and airspeed low, check the height, select full power and roll upright to the wings level and lower the nose to the horizon.*

2. *With a nose low attitude and airspeed increasing, select engine to idle, airbrake out if required e.g. 200K or more and roll upright to wings level before pulling the nose up to the horizon.*

Factual Information

> 3. *With a high nose attitude and airspeed below or going below 100 knots, leave the power set and place both hands on the control stick and hold central. Brace the rudders and wait for the nose to drop and follow the nose attitude low, airspeed increasing recovery.*
>
> *Do not pull through if the safety gate height has not been achieved but follow the unusual position recovery actions to 'unload' any 'g' forces, roll rapidly to nearest horizon, and pull to a straight and level attitude.'*

His technique for performing a loop in the Jet Provost was to increase g[4] slowly with full power and no flap selected. The g-meter[5], or accelerometer, could be used to calibrate the pilots 'feel' for the manoeuvre.

The pilot had built up a sequence of aerobatic manoeuvres in the Jet Provost that could be adapted for a particular venue, wind or obstructions. This was written down but he commented that he would not be looking at it during a display.

The pilot could not remember any of the heights and speeds used when he flew the Harrier aircraft in the RAF. Aerobatics were not a significant part of flying the Harrier except as part of general handling and as a 'building block' for air combat manoeuvring.

1.5.1.3 Hunter flying

In 2011 the pilot began training to fly the Hunter with a display team. In order to do so he was required to hold an Aircraft Type Rating Exemption (Training). This was issued on 19 May 2011 and was valid until 18 May 2012.

He carried out self-study and his instructor delivered ground training using the Hunter Aircrew Manual and Flight Reference Cards. He made five training flights, three following formation flying as a display team. The fourth was a formation transit during which the pilot conducted the majority of the handling. The fifth was a dedicated single aircraft 'Final Handling Test' (FHT). His log book entries are shown at Table 1 below, with his recollection of his participation during each sortie shown in italics.

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4 Objects experience acceleration, the magnitude of which depends on the force acting on them. An object accelerated by Earth gravity will experience zero-g if in free fall, or 1 g if stationary on the Earth's surface (because the surface of the Earth is acting to restrain the object from falling further). Accelerations of more or less than 1g may be experienced by a pilot manoeuvring an aircraft. The pilot of an aircraft in straight, level flight will experience 1 g, whereas the pilot of an aircraft in a level turn banked at 60° will experience 2 g. A tighter turn will increase the g still further. The magnitude of g can also be increased by pitching the nose of the aircraft up, such as would occur in a loop.

5 A g-meter measures the normal acceleration experienced by an aircraft. A further description is given in Section 1.6.8.1.

DATE	REG	TYPE	CAPT	P1/2	Hrs/Min	NOTES
26/05/11	G-BXFI	Hunter T7	CP/INSTR	P U/T	0:50	4 Ship formation aerobatics (1 Overshoot, 1 landing) *'Familiarisation, checks, Taxi. (Demonstration Practice Forced Landing (PFL)) to overshoot, circuit/ Landing.'*
27/05/11	G-BXFI	"	"	"	0:50	5 Ship display practice Yeovilton (PFL, overshoot, 1 landing *'Checks, taxi, PFL to overshoot, circuit/ landing.'*
27/05/11	G-VETA	"	INSTR	"	0:40	5 Ship display practice Yeovilton *'Checks, taxi, little if any flying handling.'*
27/05/11	G-BXFI	"	CP/INSTR	"	0:40	5 Ship formation aerobatics (Vic takeoff, formation, DA, 1 landing). *'Checks, taxi, takeoff, majority handling, circuit/ landing, formation member 'flypast' DA, Vic/LA + changes.'*
03/06/11	G-BXFI	"	"	"	1:05	FHT/DA (2) 'Solo 'Standard' aerobatics DA. Manual flying, slow speed flight, Chivenor: PFL, manual circuit, flapless circuit, normal circuit, emergencies and navigation.'

Table 1

The accident pilot's Log Book entries covering his training flights and associated recollections.

Factual Information

Following the successful completion of his FHT, the team's instructor/examiner signed the pilot's Approved Type Rating Exemption (ATRE) application form. The ATRE was issued on 8 June 2011 and was valid until 7 June 2012. The Chief Pilot also logged four further continuation training flights with the accident pilot; two on 18 June 2011 and two on 18 September 2011, totalling 2 hours and 40 minutes.

The renewal of the ATRE was issued on 28 June 2012 and valid until 27 June 2013. The renewal was based on the applicant having a current licence and not on any specific flight training or checking requirement. Further renewals were on the same basis.

The renewal of the Hunter ATRE current at the time of the accident was approved on 27 August 2014 and valid until 27 August 2015.

1.5.1.4 Pilot's display authorisation

A pilot must hold a DA or an exemption from holding a DA in order to take part in a flying display. Civil Aviation Publication (CAP) 403 - '*Flying displays and special events: A guide to safety and administrative arrangements*' Edition 13, in use at the time of the accident[6], defined a DA as:

> *'A national document detailing the types or groups of aircraft in which a pilot is authorised to display, together with any limitations and any other specific endorsements.'*

CAP 403 defined a Display Authorisation Evaluator (DAE) as:

> *'A CAA authorised person qualified to conduct examinations and tests for the award of a DA.'*

The aircraft operator's Chief Pilot renewed the pilot's DA on 12 September 2014. The assessment was conducted using a pair of Jet Provost aircraft flying in formation, with the Chief Pilot leading and the accident pilot following throughout an aerobatic display sequence.

6 Unless stated otherwise, this report refers to CAP 403 Edition 13, published in February 2015. Since the accident, and at the time of publication of this report, there have been 4 amendments to Edition 13, the latest of which was published on 6 June 2016.

The DAE made the following assessment:

> *'Flew as No 2 in a pair's aerobatic display during the September Duxford Airshow. All aspects of close formation were smooth accurate and formation changes crisp, safe and correct. The tail chase element was again well flown with good positioning and rule following. A safe, smooth, well executed display.'*

By following a lead aircraft the pilot did not have the opportunity to demonstrate his ability to perform solo aerobatic manoeuvres in terms of safety gates, speeds, flying technique and observing minimum height requirements, nor his ability to position the aircraft correctly with respect to the display line.

During his most recent DA evaluation, on the 24 June 2015, flown in the RV-8, the pilot demonstrated his ability both to lead and to follow another aircraft in a formation aerobatic display sequence.

The DAE's assessment was:

> *'Formation leading and following demonstrated with 2xRV8's. Manoeuvres included flypasts, wingovers, loops and Cubans. All leading flown smoothly and precisely as was the "following".*
>
> *Evaluation completed at Duxford'*

In the section of his assessment entitled *'Mentoring (enter details of mentoring completed)'*, the DAE stated:

> *'Importance of mentoring and continuous monitoring discussed.'*

Pilots may hold a DA for various categories and types of aircraft. The RV-8, an aircraft with a single piston engine of less than 200 hp, was in 'Category A'. The swept-wing Hunter and straight-wing Jet Provost were in 'Category G', for single jet aeroplanes specified by type. His DA also authorised him to display 'Category B' aircraft with a single piston engine between 200 and 600 hp.

The pilot's DA, current at the time of the accident, is shown in Table 2.

Categories, Types Authorised & Minimum flypast height	Formation member	Formation leader	Tailchase leader	Tailchase member	Aerobatic category & minimum height
A/50ft	A4	A4	Yes	Yes	I/200ft
G (Jet Provost)/50ft	A4	A4	Yes	Yes	I/200ft
B/50ft	A4	A4	Yes	Yes	U/200ft
G (Hunter)/100ft	A4	A4	Yes	Yes	S/500ft
G (L-29 Delphin) /100ft	A4	A4	Yes	Yes	S/500ft

Table 2

The pilot's DA at the time of the accident

'S' – standard, 'I' – intermediate, 'U' – unlimited level aerobatics as defined in CAP 403
'A4' – advanced formation manoeuvring, with no limit to bank angle or pitch angle, involving close formation of up to 4 aircraft.

Under the regime that existed at the time, the pilot was able to renew his DA for all of the categories by renewing his DA in one of them. Consequently the DA evaluation he conducted in the RV-8 also renewed his DA for the Hunter and Jet Provost.

1.5.1.5 Displays and display practices

Table 3 below shows the number of display practices and actual displays flown in the Hunter by year, based on records provided by the pilot:

Type	2011	2012	2013	2014	2015	Total
Display Practices	3	5	0	2	1	11
Displays	4	3	0	2	5	14

Table 3

The accident pilot's Hunter displays and display practices by year

Records indicated that the pilot had flown a total of 19 hours and 25 minutes in the Hunter during flying displays, including transit time.

Table 4 shows the pilot's recorded Hunter practice and display flights in 2015, five of which took place in G-BXFI, the other in G-BVGH:

Date	Location	Type	Flight Time Hr/Min
25 May 2015	Duxford	Practice	0:50
04 June 2015	Norwich	Display	1:05
21 June 2015	Weston-super-Mare	Display	0:45*
18 July 2015	Shannon	Display	0:30
19 July 2015	Bray	Display	1:10
08 August 2015	Bruntingthorpe	Display	1:05

Table 4

The accident pilot's 2015 Hunter displays and display practice

* This display was a flight during which the pilot flew in formation with another aircraft, and did not involve solo aerobatics.

Following his Hunter display on 8 August 2015, the pilot carried out a further nine displays in the two weeks prior to the accident flight, seven in the RV-8 and two in the Jet Provost (a Mk 5 version, denoted *'JP5'*).

Table 5 shows the order in which the types were displayed.

DATE	REGISTRATION	TYPE	FLIGHT TIME Hr/Min	LOCATION
9 August 2015	G-HILZ	RV-8	0:40	Blackpool
10 August 2015	G-HILZ	RV-8	0:40	Blackpool
14 August 2015	G-HILZ	RV-8	1:25	Eastbourne
15 August 2015	G-BWSG	JP5	0:40	Eastbourne
15 August 2015	G-HILZ	RV-8	1:25	Herne Bay
16 August 2015	G-BWSG	JP5	0:40	Eastbourne
16 August 2015	G-HILZ	RV-8	2:20	Whitstable and Eastbourne
19 August 2015	G-HILZ	RV-8	No time recorded	Broadstairs

Table 5

Display flights since the last Hunter display

1.5.1.6 Minimum display heights

CAP 403 sets out the requirements for minimum heights during displays. Edition 13 stated:

> *'Minimum heights during displays'*
>
> *5.58 'All aerobatic manoeuvres, including inverted flypasts, and manoeuvres which involve pulling through the vertical are to be executed above the approved aerobatic display height. Descent below the approved aerobatic display height to the approved fly-by height is permitted once certain of capturing the aerobatic display height. Slow speed, high angle of attack flypasts are regarded as aerobatic manoeuvres from the minimum height point of view.'*

The pilot's DA stipulated a minimum height of 500 ft for aerobatics in the Hunter.

1.5.1.7 Flying display emergency manoeuvres

CAP 403 provided the following guidance for DAEs conducting the oral element of the evaluation of a candidate to establish their aerobatic display management and response to emergencies:

> *'5.17 (c) Require the applicant to describe the sequence of the display which he intends to demonstrate. Discuss the logic of his sequence, energy management of manoeuvres, the planning of the manoeuvres in relation to the aircraft limitations, the effects of density altitude, the effects of surface and upper winds and how to adjust the sequence to compensate for external constraints.*
>
> *5.17 (d) discuss the applicant's emergency planning for items such as awareness and avoidance of inadvertent stalls/spins, engine or system failures, key heights and speeds and actions if these are not achieved and changes in weather during the display.'*

The operator's Chief Pilot could not remember the detail of what he discussed with the accident pilot when he conducted his DA evaluation but believes he would have considered emergencies and may have given the pilot a simulated emergency at some point during the aerobatic sequence. He stated that he might have introduced a simulated hydraulic system failure at the apex of a loop, the correct response to which would be to roll the aircraft upright immediately. He could not remember if he had introduced this emergency at that moment with the accident pilot. The accident pilot could not recall this or other simulated emergencies during aerobatics.

The accident pilot was aware of the technique for performing a rolling escape manoeuvre at low speeds in other aircraft (his description of which appears in Section 1.5.1.2 above), and the importance of reducing the g loading on the wing until a safe speed was achieved. He had not practised this escape manoeuvre in the Hunter and commented that he would not be sure of the outcome of attempting it at the speed (105 KIAS) achieved at the apex of the accident manoeuvre.

1.5.1.8 Pilot recency requirements

CAP 403 Edition 13 set out the recency requirements for display pilots, as follows:

> *'In addition to a valid Certificate of Test and Competence, a Display Pilot is required to meet certain recency requirements before his DA is valid. In the 90 days preceding a demonstration at a flying display for which an Article 162 Permission is required, a minimum of three full display sequences must have been flown or practised, with at least one display sequence flown or practised in the specific type of aircraft to be displayed.'*

In the 90 days preceding the accident flight, the pilot had flown a total of 33 displays or practice displays: 22 in the RV-8, five in the Jet Provost and six in the Hawker Hunter; exceeding the minimum recency requirements in both total displays and displays on type.

An RAF display pilot is required to have flown two displays or practice displays in a specific type in the eight days preceding a public display.

1.5.2 The Flying Display Director

CAP 403 described a Flying Display Director (FDD) as '*The person responsible to the CAA for the safe conduct of a flying display*'. The Shoreham FDD had been responsible for previous flying displays, was a display pilot and DAE, and was formerly Head of the CAA General Aviation Department. The organiser of the flying display indicated that it had selected the FDD for his "significant experience in running air displays and his wide recognition within the air display community".

1.5.3 The Flying Control Committee

CAP 403 *'strongly recommends'* that there is a Flying Control Committee (FCC) for displays of seven or more items. It described the FCC's role as:

> *'a) to assist the FDD in monitoring display standards;*
>
> *b) to provide specialist knowledge for specific display items; and*
>
> *c) to offer in-depth opinion in the case of infringement of the regulations.'*

CAP 403 stated that the FCC should have:

> *'…the clear authority of the Event Organiser to curtail or stop, on the grounds of safety, any display item or, in extreme cases, the whole flying display.'*

The FCC at Shoreham consisted of four experienced pilots located on or near the appropriate display lines. The FDD stated that the Shoreham FCC had the written authority of the event organiser to override the FDD on any flight safety related matter and to stop any part, or all, of the flying display on the grounds of public safety.

1.6 Aircraft information

1.6.1 General

Manufacturer:	Hawker Aircraft Ltd
Type:	Hunter T7
Manufacturers serial number:	41H-670815
Year of manufacturer:	1955 as a single-seat Hunter but modified to a two-seat T7 in 1959
Total airframe hours:	5,976 at 22 August 2015
Engine:	Rolls-Royce Avon Mk 122
Certificate of Validity valid to:	10 March 2016 (issued by the maintenance organisation)
Certificate of Registration No:	G-BXFI/R7 (issued by the CAA)

1.6.2 Aircraft description

The Hawker Hunter T7 is a single-engine, swept-wing, military jet trainer capable of speeds close to the speed of sound. G-BXFI was built in 1955 as a single-seat aircraft, but was modified in 1959, with two pilot seats installed side-by-side, to become a T7 two-seat trainer. Both pilot positions were fitted with ejection seats. It was transferred to the civil register in 1997.

Figure 3

Hawker Hunter G-BXFI
(Photo courtesy N Watkin)

1.6.3 Standard configuration

Standard aircraft empty weight:	6,087 kg / 13,420 lb (including unusable fuel, oils and fluids)
Maximum permitted all-up weight:	11,340 kg / 25,000 lb
Length overall:	14.9 m
Height overall:	4.1m
Wingspan:	10.3 m
Fuel capacity[7]:	Internal - fuselage and wing, 1,882 litres / 1,505 kg External - wing drop tanks, 909 litres / 727 kg
Maximum speed:	620 kt
Load factor limitations:	+7 g / -3.75 g (negative g limited to 10 seconds)

7 Fuel weights in this section assume a nominal specific gravity of 0.8.

1.6.4 Flying controls

The dual primary flying controls in the cockpit were connected via a series of push-pull rods and bellcranks to their respective control surfaces. The ailerons and elevator were hydraulically power-assisted with manual backup in the event of hydraulic failure. Spring units were fitted to provide 'feel' to the pilot when operating in powered mode. The variable incidence tailplane was electrically operated and had a pilot-selectable follow-up trim interconnection to the elevator.

The manual aileron trim position indicator was recorded as being unserviceable.

1.6.5 Flaps

The aircraft was equipped with hydraulically-operated, electrically-controlled split flaps which could be selected to one of eight positions by the pilot.

The *'Hunter T Mk 7 & 7A aircrew manual'*, reference AP 101B-1302 & 3-15 (referred to as the Aircrew Manual), Part 2, Chapter 2 – *'Airframe limitations'*, pages 2 and 3, states:

> *'4 Speed*
>
> *The maximum permitted speeds are: …*
>
> *(e) Flaps*
>
> *Up to 38° … … … … … … … 300 knots/0.9M*
> *Full … … … … … … … … 250 knots'*

Section 3 of the Aircrew Manual, Part 3, Chapter 2 – *'Handling in flight',* paragraph 3(f) states:

> *'If the IAS limitations for the use of flaps are inadvertently exceeded, the flap angle is limited according to the air load to prevent damage, but sufficient flap is extended to create a strong nose-down change of trim. This can result in elevator jack stalling and tailplane actuator clutch slip. In this event not only is longitudinal control lost but the aircraft cannot be trimmed nose-up by either the main or the standby systems. In extreme cases, the air loads may then force the tailplane to move in opposition to the actuator thereby causing an additional nose-down change of trim.'*

1.6.6 Hydraulic system

The aircraft's hydraulic system was powered by an engine-driven pump mounted on the accessory gearbox. It provided hydraulic power to systems including the ailerons and elevator, landing gear, flaps and air brake. An alternative means of operation was provided in the event of a hydraulic system failure. A failure of the hydraulic system would have been indicated by the illumination of a red warning light on the instrument panel, an aural warning and low pressure indicated on the hydraulic pressure gauge.

1.6.7 Electrical system

The aircraft electrical system provided 24 volt (V), direct current (dc) and 115 V, 3-phase, 400 (Hz) alternating current (ac) supplies for the aircraft systems. It consisted of batteries, engine-driven generators and inverters. The system was designed to provide redundancy in case of component failures.

1.6.8 Instruments

1.6.8.1 Accelerometer (g-meter)

G-BXFI was equipped with an accelerometer, or 'g-meter', mounted just above the right instrument panel, displaying acceleration perpendicular to the aircraft's longitudinal axis using three pointers.

The g-meter operates by detecting the movements of a weight, which is suspended on two guide rails and centred by a spring-loaded control cord. When the aircraft manoeuvres, inertia acts upon the weight causing it to ride up and down on the guide rails. This movement is transmitted to the pointers by the control cord via two pulleys. One pointer indicates the instantaneous acceleration, the other two register the maximum positive and negative accelerations respectively. The pointers are reset by pressing a knob on the instrument case.

The aircraft was also fitted with a fatigue meter to record the loads applied to the airframe so that the remaining airframe life could be calculated. The fatigue meter was installed in a remote compartment and was not visible to the pilot. The fatigue state was required to be recorded after each day's flight but the maintenance organisation read and recorded the fatigue state once a year. Between these readings monitoring of fatigue relied on the pilot reporting any high loads seen on the g-meter in the cockpit.

1.6.8.2 Pitot-static sensors

A pressure head on the leading edge of the left wing tip provided pitot and static pressures for the pressure-operated flight instruments, including the airspeed indicators and altimeters.

1.6.8.3 Airspeed indicators

G-BXFI was equipped with two Munro Mk 12A airspeed indicators (ASI), mounted on the left and right instrument panels. One is shown in Figure 4.

Figure 4

Munro Mk 12A Airspeed indicator

1.6.8.4 Altimeters

General

G-BXFI was equipped with a Mk 29B and a Mk 30B Kollsman servo-operated altimeter, mounted on the left and right instrument panels respectively, which received static pressure from the aircraft pressure head.

Altimeters display altitude by comparing the pressure within the sealed altimeter case to the pressure inside an aneroid capsule[8]. As the aircraft climbs and descends, the outside air pressure, and thus the pressure in the altimeter case, changes. The aneroid capsule expands or contracts according to the pressure change. The capsule deflections are converted into rotary motion, by an arrangement of internal gears to drive a pointer on the instrument face and to display the aircraft height.

8 An aneroid capsule is a sealed, evacuated, thin-walled metal capsule.

Altimeters incorporate a means of setting a reference barometric pressure, to correct the instrument for local pressure conditions so that it indicates the height above a particular reference such as sea level or aerodrome elevation.

Traditional altimeters can be subject to error and may not respond accurately to rapidly changing altitude, because tiny capsule deflections must overcome friction in the internal gearing to generate large movements of the pointer. Servo-operated altimeters increase accuracy by using electrical devices such as synchros[9] and servo-motors to amplify and convert the mechanical displacement of the capsule into electrical signals and so drive the pointer.

A brief description of the altimeter system is presented in the following sections, and a more detailed description can be found in Appendix A.

Mk 30B altimeter (mounted on the right)

The Mk 30B[10] altimeter is a servo-operated altimeter of a type that displays pressure-corrected altitude. It operates as the master altimeter, providing an electrical signal to the left (Mk 29B) altimeter and an encoded signal to the aircraft transponder for altitude reporting.

A setting knob, or 'baro-knob', at the front of the instrument (see Figure 5), enables the reference barometric pressure to be set on the four-digit millibar (mb) counter. Rotation of this knob corrects the pressure measured by the capsule, and simultaneously rotates the millibar counter, height counter and pointer.

The height of the aircraft above the selected reference is indicated by a single-needle pointer that shows hundreds of feet and makes one complete rotation every 1,000 ft, and by a height counter in the middle of the instrument face that displays height in thousands and hundreds of feet.

The encoded altitude signal and the electrical signal sent to the Mk 29B are based on the 'standard atmosphere' reference pressure of 1013.25 mb and are not affected by the setting on the millibar counter.

In the event of an electrical failure of the Mk 30B, a red/black striped power failure flag is intended to drop into view to obscure the height counter, and the electrical signals to the Mk 29B altimeter and transponder are disconnected.

9 A synchro is an electrical device which converts a mechanical input to an electrical output, or vice versa. It comprises a rotating shaft (rotor) and a fixed case (stator).
10 Mk 30B is the UK military designation for Kollsman altimeter, part number (P/N) L.83261-04-020.

Figure 5

Mk 30B altimeter (barometric pressure setting not as found)

Mk 29B altimeter (mounted on the left)

The Mk 29B[11] left altimeter is a servo-operated altimeter that can also operate as an uncorrected precision pressure altimeter, either automatically or by selection. In normal operation ('servo mode'), the Mk 29B receives a pressure-error-corrected altitude signal from a synchro-transmitter[12] in the Mk 30B, so that it gives a more accurate indication of altitude. Operation of the baro-knob is similar to that on the Mk 30B.

A STANDBY/RESET knob, labelled 'S' and 'R', on the front of the instrument (see Figure 6) allows manual selection of the standby or servo mode. The knob is spring-loaded to the centre position. When STANDBY (S) is selected, the altimeter reverts to standby operation, an integral 28 V (dc) vibrator motor starts, to help the capsule overcome friction in the internal gearing, and an orange STBY flag appears above the height counter. When selected to RESET (R) the altimeter resets to servo mode, the vibrator stops and the STBY flag clears. When aircraft electrical power is switched off, the Mk 29B reverts to standby mode.

11 Mk 29B is the UK military designation for Kollsman altimeter, P/N L.82621-04-010.
12 In a synchro-transmitter, mechanical input (shaft rotation) is converted to an electrical output.

Figure 6

Mk 29B altimeter in servo mode (left image) and standby mode (right image). Reference barometric pressure setting not as found

The Aircrew Manual describes altimeter failure conditions that will cause the Mk 29B to revert automatically to standby operation (see Appendix A), including a failure of the electrical power supply, and gives the following advice to ensure two independent sources of altitude indication are available for critical phases of flight:

> *'When the Mk 29B altimeter is being operated in the servo (R) mode, it is possible for a fault in the system to cause both altimeters to indicate the same incorrect height without any warning flag indications. It is recommended, therefore, that the Mk 29B altimeter be selected to standby (S) for take-off and at the beginning of a descent/recovery procedure.'*

The Aircrew Manual does not state which altimeter mode should be selected for dynamic manoeuvring flight, but servo mode is the normal operational mode and provides the greatest accuracy.

1.6.8.5 RPM indicator and tacho-generator

G-BXFI was equipped with a Smiths Mk 10A rpm indicator gauge, and a Mk 8C engine-driven tachometer generator (or tacho-generator).

The rpm indicator displays the engine rotational speed between 1,200 and 12,000 rpm. The system is self-powered and driven directly by the tacho-generator, which is mounted on the engine auxiliary gear box.

1.6.8.6 Engine exhaust gas thermometer

The exhaust gas thermometer provided a continuous indication of engine exhaust temperature, also referred to as Jetpipe Temperature (JPT), from 0 to 1,000°C.

1.6.8.7 Transponder

G-BXFI was equipped with a Becker ATC 2000-3-R civilian transponder, which suffered extensive damage during the accident and could not be tested.

1.6.9 Rolls-Royce Avon Mk 122 engine

The Rolls-Royce Avon Mk 122 is an axial flow engine which produces a maximum thrust of 7,575 lb at 8,100 rpm. The engine has a 12-stage compressor with variable inlet guide vanes, eight combustion chambers and a two-stage turbine. High pressure air is bled from either the 8th or 12th stage of the compressor to supply aircraft systems. The delivery of bleed air and compressor airflow is controlled by a Bleed Valve Control Unit (BVCU).

Fuel supplied by low pressure pumps in the fuselage fuel tanks passes through a fuel filter in the Fuel Control Unit (FCU) before reaching the engine-driven dual-swashplate fuel pump, shown in Figure 7. The supply of high pressure fuel from the pump is controlled by a servo fuel system which consists of a hydro-mechanical governor (within the fuel pump) an Acceleration Control Unit (ACU) and a Barometric Pressure Control (BPC) unit.

The FCU contains the high pressure fuel shut-off cock and the fuel metering valve. The fuel metering valve, connected to the throttle levers via a cam box in the fuselage, varies the fuel flow to the fuel nozzle in each combustion chamber to produce the commanded thrust. If the engine exhaust temperature exceeds 690° C the fuel supply to the nozzles is automatically restricted by the solenoid operated Fuel Dip Unit. In military service, when the aircraft had been fitted with a 30mm Aden cannon, the engine was fitted with a Gun Dip system. This restricted the fuel flow to the fuel nozzles when the gun was fired, to prevent compressor surges. This system was deactivated when the cannon was removed from the aircraft during its military service.

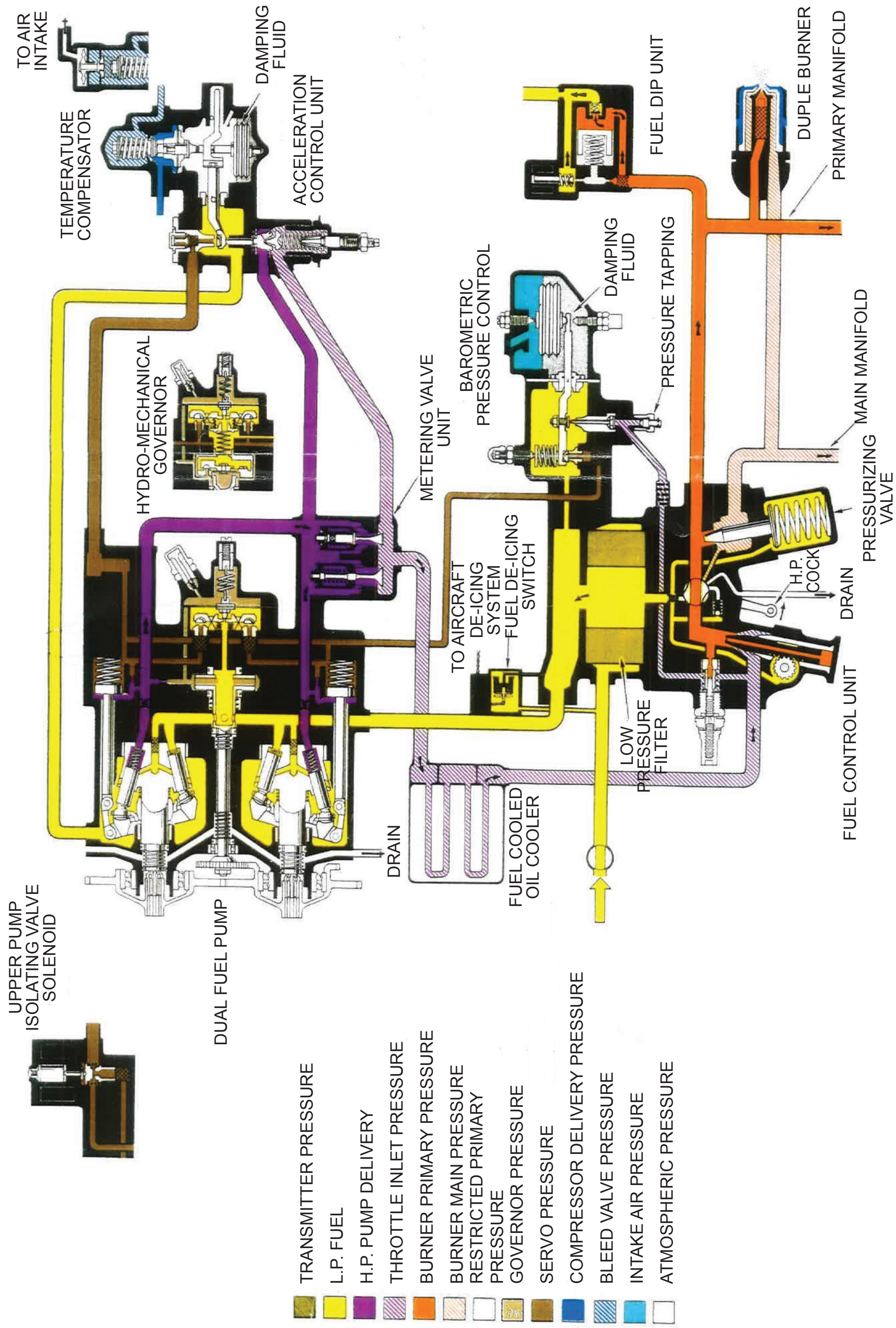


Figure 7

Rolls-Royce Avon 122 fuel control schematic diagram

1.6.10 Aircraft fuel system

Fuel was carried in twelve internal tanks, four in each wing, and two front and two rear tanks in the centre fuselage. G-BXFI was also fitted with two 100 gallon underwing tanks, constructed from asbestos-reinforced phenolic resin, mounted on the inboard pylons. Fuel was fed to the engine by a booster pump in each front tank. In normal operation the booster pumps were switched on before engine start and remained on until immediately before engine shutdown. Fuel was automatically transferred from the other fuel tanks using pressurised air bled from the engine's compressor. The system was designed to empty the fuel tanks in the following order: underwing tanks, wing tanks, rear fuselage then forward fuselage. A warning light in the cockpit was intended to illuminate when each forward tank contained less than 650 lb of fuel.

1.6.11 Pilot escape system

G-BXFI was equipped with two Martin-Baker Mk 4HA ejection seats[13]. The design is capable of safe ejection at ground level, if the aircraft's flight path is parallel to the ground and it has a forward speed of at least 90 kt. The minimum safe height for ejection from an aircraft that is descending is approximately 100 ft above ground level for every 1,000 feet per minute rate of descent when upright.

Each seat is mounted on an ejection gun, which uses pyrotechnic cartridges to provide the propellant power for the ejection. The ejection gun comprises three telescoping tubes; inner, outer and intermediate. A firing unit containing the primary cartridge is located at the top of the inner tube and two secondary cartridges are mounted in the outer tube. The outer tube is attached to the aircraft structure via a 'bottom fitting' which is bolted to the cockpit floor, and a 'top fitting' bracket attached to the rear cockpit bulkhead. The seat is connected to the ejection gun via a spring-loaded plunger, which engages in a locking collar on the inner tube, through a 'top-latch' window on the outer tube. Three sets of steel 'slippers' on either side of the seat structure engage in guide rails mounted to each side of the outer tube.

The canopy is jettisoned automatically whenever ejection is commanded. Canopy jettison can also be initiated separately by pulling the canopy jettison handle at the rear of the centre pedestal.

Under normal conditions, ejection is initiated by pulling either the face-screen firing handle located above the pilot's head, or the Seat Pan Firing Handle (SPFH), fitted to the front of the seat pan between the pilot's legs. This causes the canopy cartridge to be fired followed, after a 0.5 second delay, by the

13 The ejection seats are described in more detail in Appendix B.

primary cartridge. The resulting gases pressurise the ejection gun tube which extends, unlocking the seat from the aircraft and uncovering the secondary cartridges, which fire as they become exposed to the hot gases. As the seat rises up the guide rails, the remaining elements of the ejection sequence are mechanically-activated by static rods, and time delay mechanisms ensure the correct sequence occurs.

The drogue gun cartridge fires and deploys a main and controller drogue, which inflate to retard and stabilise the seat as it falls. The ejection seat scissor-shackle releases, transferring the pull of the drogues to extract the pilot's parachute. The pilot's harness locks and leg restraint lines release, separating the pilot from the seat. The main parachute canopy inflates and the pilot is rapidly decelerated, and can descend under the parachute as the seat falls away separately.

If the seat fails to eject or if automatic seat separation is not achieved following ejection, the pilot can pull a manual separation handle on the left side of the seat pan to release the harness locks and leg restraint lines. As the seat falls away, a cable between the pilot's parachute and the seat acts to release the firing pin in the guillotine firing unit. As the cartridge fires, a small guillotine blade severs the line connecting the drogues and main parachute canopy[14]. The pilot is then fully separated from the seat, and can manually pull the parachute rip-cord handle to deploy the main parachute canopy.

1.6.12 Pilot anti-g system

The aircraft had an anti-g system which consisted of high pressure air bottles connected to the anti-g trousers worn by the pilots. It comprised a filter, an ON/OFF selector valve, a pressure-reducing valve, and an anti-g valve to control the air pressure to the anti-g trousers automatically according to g loads when they exceed 2.5g. The pilot was wearing anti-g trousers at the time of the accident.

The technical manual for the aircraft states:

> *'The use of an anti-g suit raises the pilot's blackout level and considerably reduces fatigue caused by repeated applications of G and enables the pilot to carry out 'all round' observations at high G.'*

14 The guillotine cartridge also fires during automatic seat separation, but the parachute withdrawal line is pulled out of the guillotine gate when the drogues deploy, and is therefore not severed.

1.6.13 Mass and centre of gravity

The maximum permitted all-up mass (MPAUM) for the aircraft was 25,000 lbs. The forward centre of gravity (cg) limit was 1.0 inch forward of the cg datum and the aft cg limit, 14.5 inches aft of the datum.

The aircraft mass and cg prior to start was calculated as 18,814 lbs, with full fuel and a pilot weight of 180 lbs, producing a cg position 3.71 inches aft of the datum. Assuming the estimated fuel use detailed in the flight trials report (see Section 1.16.1) the total mass at impact was estimated to be 17,600 lbs with a cg position 3.97 inches aft of the datum.

Therefore, the aircraft was being operated within the MPAUM and cg limitations set out in the Hunter T Mk 7 Aircrew Manual.

1.6.14 Maintenance records

1.6.14.1 General maintenance and CAA audits

When G-BXFI was accepted on to the civil register in 1997, maintenance activity had been planned using the aircraft's military maintenance programme and recorded on documents based on original military documentation.

Since 1997 the aircraft had been operated and maintained by a number of organisations, which, up to 2011, had used maintenance programmes based on the Hawker Hunter T7 Master Servicing Schedule[15]. It had a non-expiring Permit to Fly issued on 17 October 2003 (see Appendix C). In 2011 the aircraft changed ownership and the nominated maintenance organisation elected to change the aircraft's maintenance programme to a bespoke programme based around an annual "minor check", and a "major check" every two years, each incorporating tasks from the original maintenance programme.

A flight test was conducted on 26 June 2011 as part of the Permit to Fly revalidation process, during which engine speed was recorded on the flight test form to have exceeded the limit of 8,100 ±50 rpm several times: 8,250 rpm on three occasions and 8,350 rpm once. There was no evidence of these exceedences being reported in the technical log or of any inspections or remedial action being taken, and the flight test was signed off by the pilot involved as, *'airworthy and functionally serviceable to the required standards'*.

When the aircraft was purchased by the current operator in July 2012, it was flown from St Athan, South Wales, to North Weald to undergo maintenance. After arrival at North Weald the current maintenance organisation completed

15 Air Publication AP101B-1300-5A1. This document was the basis for the aircraft's maintenance schedule.

an inspection of G-BXFI's maintenance records. Due to a lack of clarity regarding the aircraft's maintenance status, and after discussion with the CAA, the maintenance organisation decided to transfer the aircraft back onto a maintenance programme based on the original military programme and to track maintenance activity using military-style documents.

In order to ensure that the aircraft met regulatory requirements it underwent a 'Minor Star' inspection (see Table 13). This was completed in December 2012. The subsequent application recommending the issue of a Certificate of Validity (C of V) for its Permit to Fly was accepted by the CAA which then issued the C of V. During this maintenance input the maintenance organisation's approvals were subject to an audit by the CAA, the report of which the CAA has not provided to the investigation.

On 3 January 2013 the CAA conducted an Aircraft Continuing Airworthiness Monitoring (ACAM) audit of the aircraft. A specific item on the audit checklist referred to compliance with MPD 2001-001, an MPD imposing a calendar life on the engine with an option to extend that life using an AMOC approved by the regulator (see Section 1.18.14). The audit report stated:

> *'MPD 2001-001 complied with 2009, the next permit renewal was Dec 2012, although in compliance no entry made in aircraft record. Entry made in aircrafts 700* [maintenance log] *for MPD before next flight, aircraft had not been released to service.'*

There was no specific reference to an AMOC to MPD 2001-001 in the audit report.

In November 2013 the maintenance organisation issued a new Certificate of Validity for GBXFI's Permit to Fly, valid from 28 November 2013 until 4 December 2014 (see Section 1.17.8). Between November 2013 and the end of March 2014 the aircraft underwent a 'Primary' inspection. Between December 2014 and March 2015 the aircraft underwent another period of scheduled maintenance which included a 'Primary Star' inspection.

The CAA conducted an audit of the maintenance organisation's BCAR[16] A8-20 approval in November 2014. This included a review of the issue of G-BXFI's Certificate of Validity for its Permit to Fly. There were no findings.

In March 2015 the maintenance organisation certified another Certificate of Validity for G-BXFI's Permit to Fly, valid from 11 March 2015 until 10 March 2016. After completion of the maintenance input the aircraft was subject to a post-maintenance 'shake down' flight on 20 March 2015 after which the pilot reported verbally that the aircraft had a number of technical defects, including a problem with the right altimeter.

16 British Civil Airworthiness Requirements.

1.6.14.2 Altimeter maintenance records

There were no defects relating to the altimeters recorded in the aircraft's technical log. However, a maintenance work order indicated that the Mk 30B (right) altimeter had been replaced on 23 March 2015. The maintenance organisation advised the AAIB that this work was undertaken as the result of a verbal defect report by one of the pilots following a post-maintenance flight on 20 March 2015. The maintenance work order stated:

> *Master altimeter servo encoder 30B not working in flight.'*

The maintenance work order also indicated that the altimeter would not power-up during subsequent maintenance. The maintenance organisation determined that the fault was linked to inconsistent electrical power supply to the altimeter, due to the compass unit drawing excessive current.

The maintenance work order stated:

> *'U/S* [unserviceable] *altimeter #993 replaced with serv* [serviceable] *altimeter #874. Pitot static checks carried* [out] *from pitot probe to unit satis* [satisfactory]*.'*

The maintenance work order indicated that the pitot-static system had been leak-tested after replacement of the altimeter. The maintenance organisation informed the AAIB that the replacement Mk 30B altimeter was taken from another Hawker Hunter, G-BZSE, which was undergoing refurbishment in its facility. The maintenance organisation was unable to confirm when G-BZSE had last flown, but its most recent Certificate of Validity expired in 2011.

The investigation determined that the Mk 30B altimeter fitted to G-BXFI at the time of the accident was in fact S/N 786 and not S/N 874 as the maintenance records indicated. The maintenance organisation informed the AAIB that the altimeter taken from G-BZSE was the only spare altimeter available to it and indicated that the serial number on the work order had been transcribed in error.

No functional test of the altimeter system, to confirm electrical synchronisation between the two altimeters, was carried out after replacement of the Mk 30B altimeter. There were no pilot reports regarding the altimeters following the replacement of the right altimeter and the maintenance organisation stated that it had no other means of knowing if there was problem with the altimeters. There were no further entries in the technical records relating to the altimeters.

The maintenance organisation sent the Mk 30B altimeter S/N 993, removed from G-BXFI, to a repair facility for further investigation. The associated repair documentation indicated that the travel-limit micro-switch had activated (see Appendix A for a description of this failure condition). This had most likely occurred due to the baro-knob being wound excessively when the altimeter was unpowered, either in flight or during maintenance trouble-shooting of the reported defect. The repair facility adjusted the baro-knob to reset the micro-switch and subjected the altimeter to the manufacturer's standard test schedule. No additional anomalies were observed, and the unit was declared serviceable and returned to the maintenance organisation.

The maintenance organisation did not keep component log cards for the altimeters and stated that it did not have access to historic component log cards in the aircraft records. It was therefore unable to determine the history of the altimeters or the date of their last service.

1.6.14.3 Engine maintenance records

The engine and airframe manufacturers' documentation required engine removal after 450 flying hours for a 'hot section inspection', and an overhaul after 900 flying hours. Records indicated that the engine's last workshop visit, a 'hot section inspection', had been completed in 1990 and, at the time of the accident the engine had completed 846 flying hours.

The log card for the high pressure fuel pump (see Appendix D) showed that the pump had been overhauled in 1988 and had operated for 269 hours at the engine's last workshop visit in 1990. There was no additional information available to identify any other maintenance activity associated with the fuel pump.

There were no recorded defects relating to the engine or its systems.

1.6.14.4 Ejection seat maintenance records

Ejection seat maintenance is discussed in Section 1.18.15.3.

1.7 Meteorological information

On the day of the accident the south-east of England was under the influence of a stable southerly airflow. Satellite images showed that the area was free of significant cloud from the time of departure from North Weald to the time of the accident near Shoreham. Surface observations indicated 'CAVOK' conditions (no cloud below 5,000 ft and visibility in excess of 10 km), with surface winds in a south or south-easterly direction at approximately 10 kt, increasing steadily with height to approximately 16 kt at 5,000 ft.

1.8 Aids to navigation

Not applicable

1.9 Communications

The AAIB reviewed recordings of the radio transmissions between the pilot and North Weald Radio, Farnborough Lower Airspace Radar Service East, Shoreham Approach and Shoreham Display frequencies. The relevant content indicated an altitude check in the climb (see Figure 11) and the pilot's intention to climb slowly to 2,000 ft during the southerly track. The relevant QNH given during the transit was 1013 and the QFE[17] and QNH for Shoreham at the time of the accident was also 1013. There were no transmissions on the Shoreham Approach or Display frequencies during the accident display sequence.

1.10 Aerodrome information

Shoreham Airport is located 1 nm west of Shoreham-by-Sea. It has four runways: an asphalt surfaced main runway orientated 02/20, 1,036 metres long with a width of 18 metres, and three grass runways, 02/20 (Grass), 07/25[18] and 13/31. The airfield is 7 ft above mean sea level (amsl).

On 22 August 2015, a large organised flying display was being undertaken with the minimum separation of aircraft from the crowd being determined by aircraft speed and the type of display being flown. The relevant display axis for G-BXFI was 230 m from the crowd line, parallel with and broadly west of the main runway. The extended centreline of the display axis passed through the junction of the A27 and Old Shoreham Road.

Restrictions were in place directing pilots not to overfly residential areas at Lancing below 1,000 ft, Shoreham Beach and an industrial area to the north below 500 ft, or Lancing College buildings at any height.

A copy of one of the 2015 Shoreham Airshow display maps provided to pilots is shown in Figure 8.

17 QFE is the reference barometric pressure set on an altimeter in order to display height above a particular aerodrome.
18 The published runway designator changed to 06/24 on 24 June 2016.

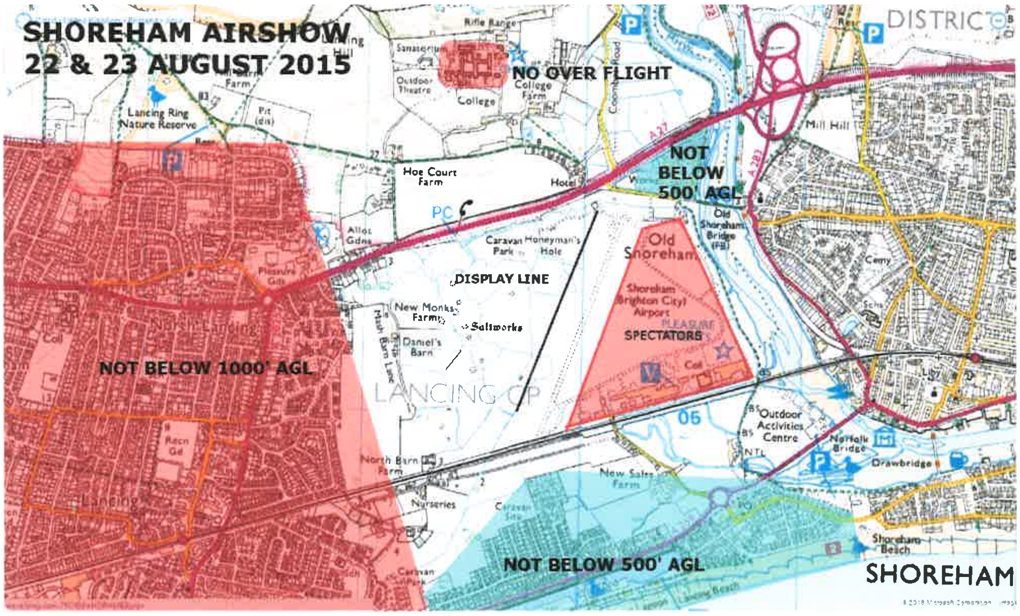


Figure 8

2015 Shoreham Airshow display map.
(The single display line indicated is not necessarily at the distance from the crowd required by G-BXFI)

1.11 Recorded data

1.11.1 General

The flight was recorded by two action cameras recovered from the cockpit. Other relevant information was recorded by a smartphone. External sources of recorded data included radar tracks, radio transmissions and many videos and photographs taken from locations on the airfield and the surrounding area. The aircraft was not fitted with a crash-protected flight recorder, and none was required.

Sections 1.11.2 to 1.11.5 describe the sources of the data. The amalgamated data associated with different aspects of the investigation is then considered in Section 1.11.6. Section 1.11.7 onwards includes data from other flights.

1.11.2 Air Traffic Control radar

NATS[19] provided radar tracks recorded by Gatwick, Heathrow, Debden and Pease Pottage radar heads. Pease Pottage provided the best source of radar data for this flight, and had a 6.2 second sweep period[20]. The recorded track of G-BXFI started at 1206:32 hrs, 14 km southeast of North Weald Airfield, with the aircraft transponder reporting a pressure altitude of 1,100 ft, slowly climbing and tracking in a southerly direction. The last recorded radar point was at 1222:19 hrs.

The rotational speed of air traffic control radar antennas is such that the information they receive is not updated sufficiently frequently for accurate tracking of aircraft that are continuously changing direction and speed.

Errors associated with aligning the recorded radar track with specific points on the ground include random errors and systematic errors. These vary for the different radar heads for a given aircraft track and complicate the mixing of positional data from different radar sources. Pressure altitude data, referred to as ‘Mode C’, from different recorded radar tracks can be more readily combined as this information is transmitted from the same aircraft's transponder.

Some of the Mode C altitude data was automatically flagged by the system as ‘Not-validated’, including a significant proportion of altitudes recorded during the accident display. However, this ‘Not-validated’ radar data appears reasonable when compared with the validated radar data and other evidence, such as the motion captured by imagery and results of photogrammetry analysis. Radar data validation is discussed further in Section 1.16.2.

Pertinent radar data is provided in Figure 10 and Figure 11.

Radar recordings were also provided for other aircraft at the same display and other displays by the accident aircraft.

1.11.3 Action cameras

Two action cameras were recovered from the wreckage. One had been mounted in the cockpit close to the windscreen, pointing forward and to the left. Specialist techniques were required to extract video files from the data recovered from this camera. The recording started in the vicinity of Brighton and ended at impact. It provided a useful visual portrayal of the parts of the flight where the terrain was in the camera’s field of view, but distortion of the image by the windscreen reduced its value for further analysis.

19 The national air traffic services provider.
20 The sweep period of a radar head is the time it takes to scan 360° horizontally. In the case of Pease Pottage this would cause the radar to beam to pass a particular point once every 6.2 s.

The second action camera was mounted on the rear bulkhead of the cockpit between the seats pointing forward and is referred to hereafter as the cockpit action camera. It captured a portion of the instrument panel, and a portion of the view through the canopy and windscreen (see Figure 9). Files recovered from the unit captured two periods of the accident flight; the first included the takeoff and initial climb from North Weald, the second started in the vicinity of Brighton and ended approximately 23 minutes after the accident.

The images included a part of the ASI, some of the fuel system controls and indicators, some of the oxygen system controls and indicators, the JPT indicator, and occasionally the engine rpm gauge when the pilot moved sufficiently for it to come into view[21]. Determining their indications was complicated by image resolution, contrast and partial obscuration. The altimeters, thrust levers, and many other indicators and controls, were not in the camera's field of view.

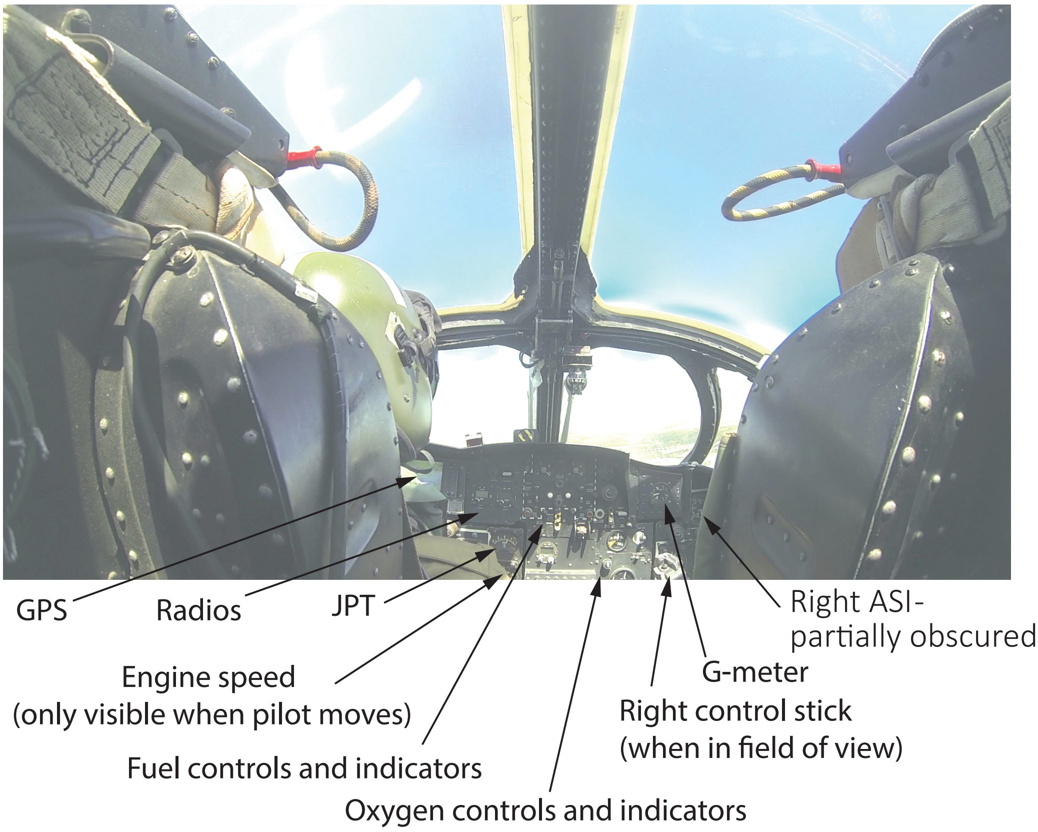


Figure 9

Cockpit action camera field of view (image lightened for this illustration)

The cockpit action camera audio recordings captured ambient aircraft noise, mostly from the engine. Relatively quiet sources of audio such as speech during radio transmissions were not detected.

21 This was the source of airspeed and JPT information.

The engine manufacturer provided details of the rotating parts of the engine and the aircraft auxiliary gearbox was stripped to identify key features to assist a spectrum analysis of the audio recording. The spectrum analysis conducted by the AAIB identified a strong signature that correlated with expected engine shaft speeds during the takeoff and transit to the south coast. Other signatures correlated with the first stage compressor blades and the rotational speeds of engine-driven gearbox components. The engine speed data derived in this manner is hereafter referred to as the 'audio rpm'.

The data derived from the in-cockpit video is shown in Figure 11.

1.11.4 Flying display videos and photographs

Members of the public provided videos and photographs associated with the accident flight. Some of these were from locations on the airfield and others were from locations in the surrounding area.

The Ministry of Defence (MOD), at the request of the AAIB, analysed the imagery using photogrammetry techniques to determine speed and positional information. It also established that the aircraft flap angle relative to a local datum line[22] running between the tip of the aircraft's nose and the centre of the jetpipe was 11° ± 3°. Visually this appeared to be similar to that used during the equivalent manoeuvre flown at Shoreham in 2014.

The imagery was also used to assess a vapour plume emanating from the right wing (see Section 1.12.3.11).

Imagery relating to other flying displays was also obtained.

1.11.5 Smartphones

A recovered smartphone contained an aviation application (app) that recorded a flight track associated with the accident flight. This relied on positional information generated by the smartphone which was probably based on Global Navigation Satellite System (GNSS) technology. It recorded the takeoff and southerly track of the aircraft, showing the transit climbing to approximately 2,000 ft amsl. However, no valid positional data was available after crossing the coastline near Brighton, with the exception of a brief period prior to the display. The pertinent data is shown in Figures 10 and 11. Further data was recorded at the accident site after the accident, probably associated with periods when the phone could receive sufficient GNSS signals to provide data to the app.

22 The flap angle is normally referenced to the wing chord line so the incidence angle of the wing, 1.5°, needs to be subtracted from this figure to compare with angles associated with the flap selection.

A smartphone situated inside a manoeuvring aircraft may lack valid positional data. GNSS technology relies on tracking weak signals from multiple satellites and using combinations of these to calculate a device's position. Without antennas that continually have good sight of a large area of the sky, satellite navigation systems can become inaccurate or stop providing positional information altogether during dynamic manoeuvres.

1.11.6 Data recorded during the accident flight

The cockpit action camera captured the indications of several systems. The only indication of a malfunction was that the g-meter was not appropriately responding to the manoeuvres flown (see Section 1.12.3.7).

The cockpit fuel gauges (indicating the combined contents of the wing, front and rear tanks but not fuel in the drop tanks) were both indicating full (more than 1,500 lbs each side) at the end of the flight. The tank pump switches were set to ON. None of the indicators relating to low fuel pressure, fuel transfer failure or tank pump failure were active during the flight (though this is not evidence of the serviceability of the indication system itself).

The guarded switches that were in view remained guarded. The elevator power controls indicator was inactive signifying that hydraulic power was ON.

The oxygen system was set to NORMAL OXYGEN, and the indicators showed the system was more than half full, pressurised to approximately 300 psi and provided regular periods of flow to the pilot.

Figures 10 and 11 combine the evidence from the radar recordings, radio telephony, smartphone recordings, imagery and audio analysis. The photogrammetry results and data derived from it are shown in Figures 12, 13 and 14.

The aircraft took off from North Weald Airfield at 1204 hrs. The pilot occupied the left seat. Cockpit video indicates rotation was initiated at 112 KIAS. The pitch attitude was subsequently reduced and then increased again before the aircraft lifted off the runway.

During the flight from North Weald to the south coast, radio communications of altitudes, probably made with reference to the left altimeter, indicated the pilot's intent to climb to 2,000 ft during the southerly track and a QNH of 1013. The radar Mode C data, based on information from the right altimeter, indicated a slow climb to the cruise at pressure altitudes around 2,000 ft. The GNSS altitude data was consistently 50 ft to 200 ft higher than the Mode C altitudes during the transit to the south coast, the difference being due to a combination of errors from both systems.

During the takeoff and climb to 2,000 ft, action camera images of the ASI and smartphone-derived groundspeed data were available. During the acceleration along the coast prior to turning inland to commence the display, images of the ASI and radar data suitable for groundspeed evaluation were available. In both cases, the recordings indicated a better-than 15 kt correlation between ASI indications and derived ground speeds.

The accident occurred at the end of a manoeuvre involving both a pitching and rolling component. The pull-up at the start of this manoeuvre commenced at an indicated airspeed of 310 ±15 KIAS[23] and from a height of 185 ±35 ft agl[24], approximately 900m from the display line and approaching it at an angle of approximately 25°. The aircraft reached an altitude of approximately 2,700 ±200 ft amsl[25] at the apex of the manoeuvre, with an indicated airspeed of 105 ±2 KIAS. Flaps were deployed throughout the looping manoeuvre.

The cockpit video indicated increased vibration in the final 5.5 seconds before initial impact.

The videos showed a slight roll to the left starting approximately 2.3 seconds before initial impact. The imagery did not show the aileron position leading up to this clearly, but did show corrective aileron inputs after this. External imagery showed the elevators deflected in the nose-up pitch sense during this time.

Head movement indicated that the pilot remained conscious and active throughout the manoeuvres.

The action camera mounted close to the windscreen stopped recording on impact. The other camera continued recording. The audio recording captured some of the speech associated with the emergency services attending the pilot, mixed with varying amounts of ambient noise.

The pilot was asked several questions by emergency personnel. The answers included some clear "No" responses. When asked whether he had felt unwell before the crash, the answer was not clearly recorded. Eight AAIB investigators were asked independently to transcribe a short section

23 The ground speed derived from photogrammetry was also 310 ±15 kt (see Figure 12). Allowing for a reported 10 kt south-easterly wind this correlates closely with the indicated airspeed recorded by the cockpit action camera.

24 Height at the start of the pull-up was derived from photogrammetry based on imagery with clear ground references.

25 The apex altitude was derived by using the following: radar Mode C altitude data (Figure 11), knowledge of the Mode C validation process (Section 1.16.2), testing of the altimeter encoding system (Section 1.12.3.6), the behaviour of Mode C data during flight trials (Section 1.16.3), expected pull-through height loss established through flight trials (Section 1.16.1) and indications from photogrammetry data (Figure 14).

of recording. Regarding the question about feeling unwell, four believed the response was in the negative and four in the positive. The recording was not conclusive in this regard and did not provide evidence of the pilot's understanding of the question he was answering or his ability to answer it accurately.

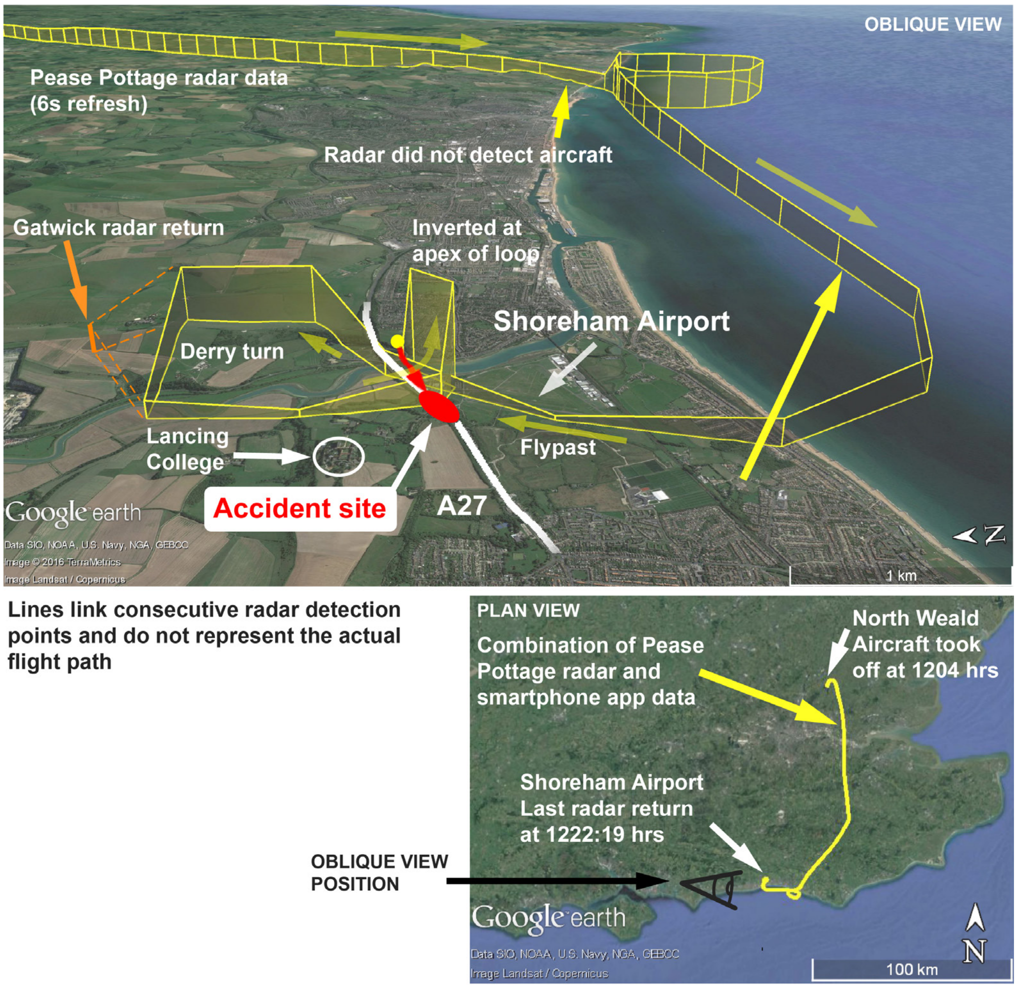


Figure 10

Overview of the flight

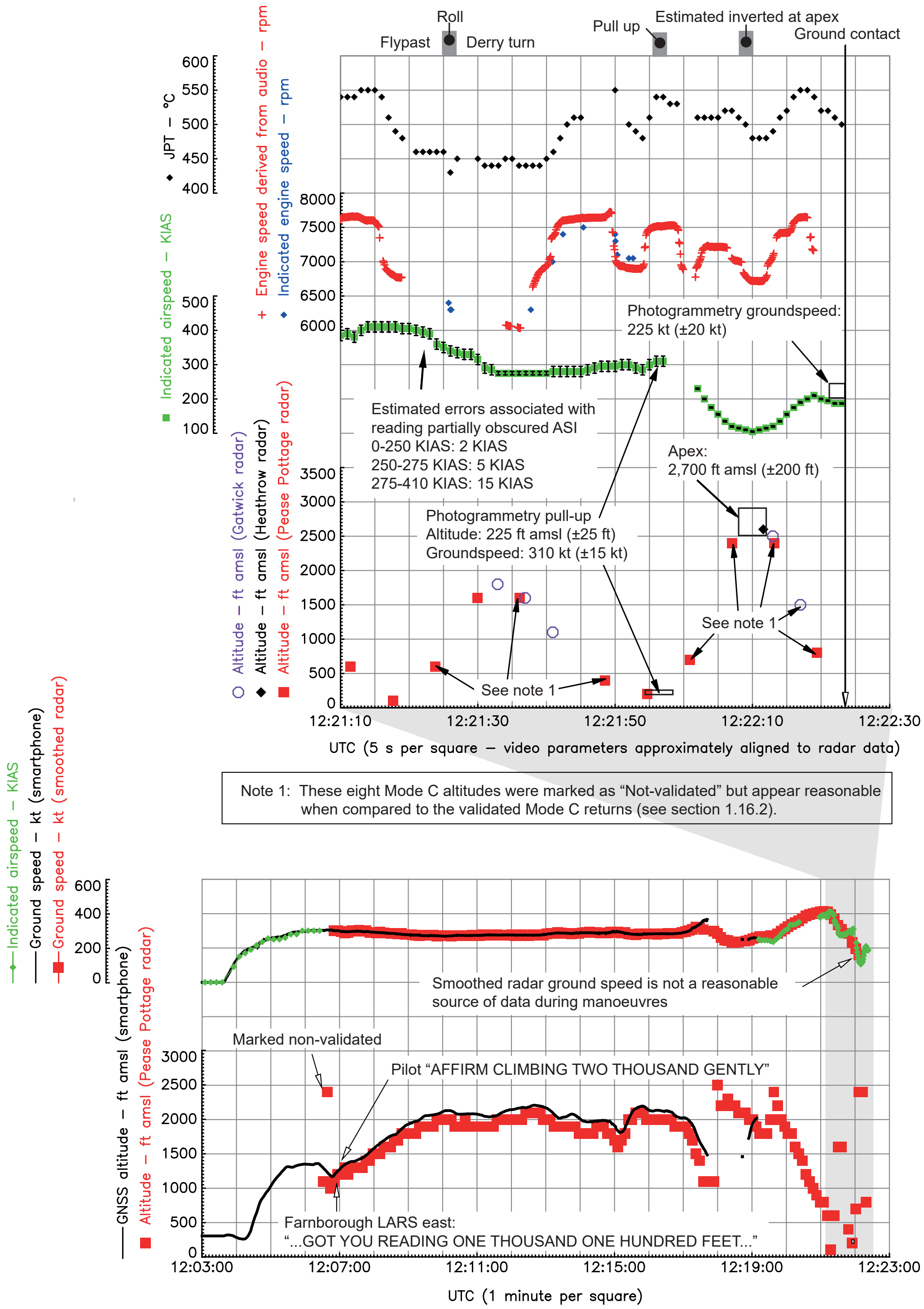


Figure 11

Flight parameters

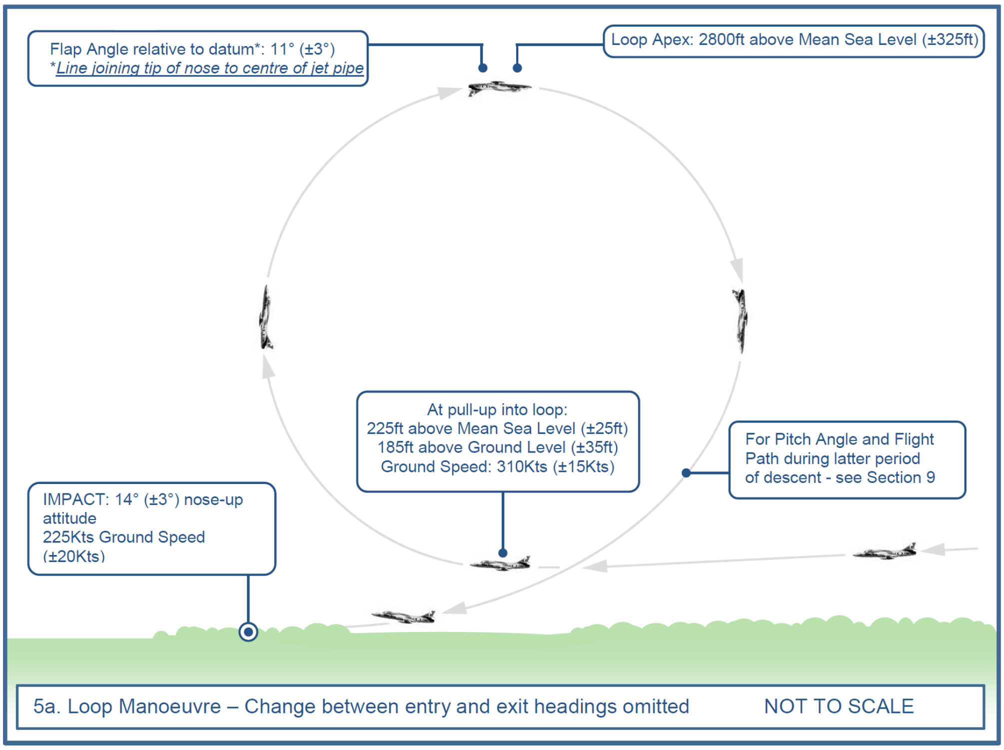


Figure 12

An extract from the MOD photogrammetry report showing a schematic representation of the accident manoeuvre. The change in heading is not shown

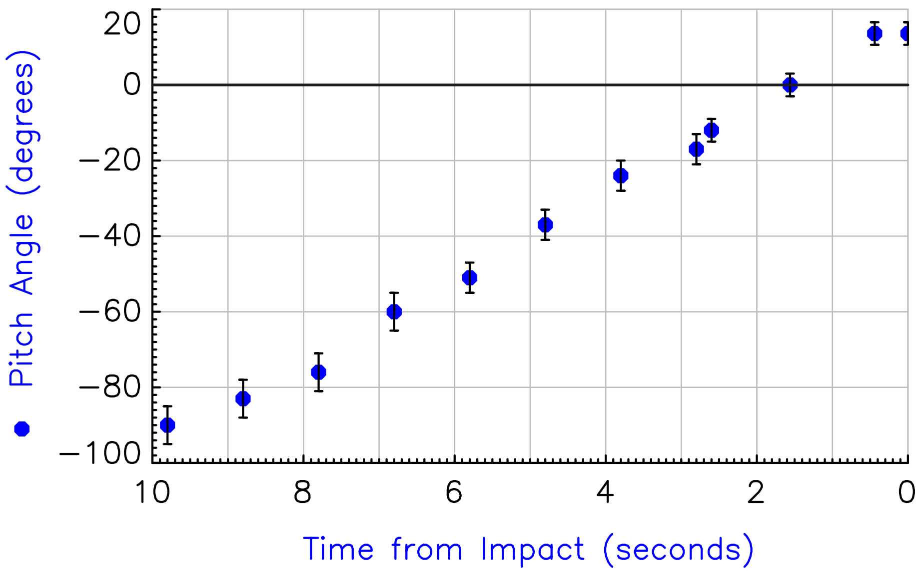


Figure 13

Pitch angle data in the last 10 seconds of flight. Data extracted from the MOD photogrammetry report

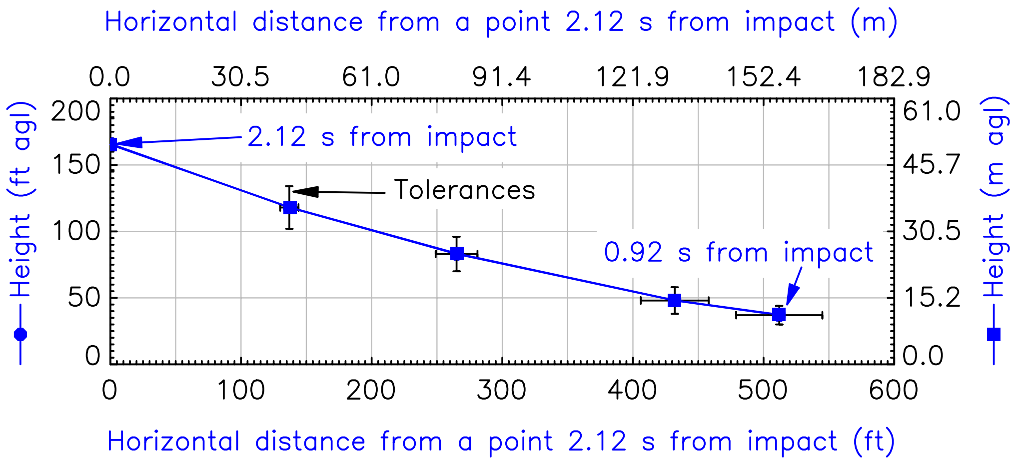


Figure 14

Flight path geometry during the final seconds of the descent.
Data extracted from the MOD photogrammetry report

1.11.7 Data recorded during previous flights

1.11.7.1 General

Cockpit video recordings were obtained of two previous displays in which the accident pilot flew the same aircraft. The camera mounting locations were different in each case, allowing different aspects to be reviewed. Sections 1.11.7.2 and 1.11.7.3 describe specific findings pertinent to each flight and subsequent sections draw on these videos to compare common aspects such as engine usage.

External video recordings of both these flights were obtained.

Cockpit video recordings of the accident pilot displaying a Jet Provost on the Saturday and Sunday of the weekend prior to the accident were also provided to the AAIB. Section 1.11.7.4 provides the entry and apex values for loops flown during these displays.

1.11.7.2 Shoreham – August 2014, G-BXFI

The cockpit action camera captured throttle lever movements, the rpm indicator, the JPT indicator and other instruments. This provided evidence of the engine rpm/JPT relationship, the engine rpm changes in the climb phase of loops, and a comparison between the throttle movements and the engine rpm data sources.

The cockpit action camera did not capture airspeed or altitude indicators. The Mode C function of the transponder was switched OFF, so the radar recording did not provide any altitude data. The manoeuvres included a modified loop (described in more detail by the Test Pilot in Section 1.18.3.3). The cockpit video shows throttle movements that correlate strongly with the shape of the audio rpm signature. The rpm gauge appeared initially to react quickly to engine speed changes but did not reach the stable audio rpm values.

The cockpit action camera captured movement of the right throttle lever, which is mechanically linked to the left throttle lever used by the pilot. Throttle position varied during the climb phase of the loop.

Only half the g-meter was captured in the cockpit video, which initially showed movement of all three needles. For the majority of the recording only the main and peak negative load needles were captured, neither of which moved after the initial three manoeuvres, regardless of the rolls, turns and manoeuvres flown subsequently.

1.11.7.3 Duxford – September 2014, G-BXFI

During the display of G-BXFI at Duxford in 2014 an internal camera mounted on the inside of the canopy captured the instrument panel and an external view. Both altimeters were captured with an image resolution sufficient to read the needles but insufficient to read the numbers on their height counters. The instrument images often suffered from poor lighting and the view of the left altimeter was from an oblique angle.

This section references the right hand altimeter readings, which indicated approximately 0 ft on the ground before and after the display. The video is an amalgamation of a number of non-contiguous periods, starting with the taxi out and takeoff, a display flying period and the approach, landing and taxi in.

An external video, taken from a location on the crowd line, afforded a view of the flaps and airbrake during most of the aircraft's display.

Some pertinent instrument readings extracted from the recordings are provided here. Section 1.18.3.2 contains a more detailed description provided by the Test Pilot.

The recorded manoeuvres included a loop. The climbing phase of the loop was carried out with the airbrake deployed. This started at 200 ft aal, peaked at approximately 4,250 ft aal, when the airbrake was stowed, and ended at 400 ft aal. It was not clear if the aircraft could have completed the manoeuvre above this height had the pilot chosen to do so. The speed indication on entry to the loop could not be established but was increasing prior to the last visible speed indication of approximately 320 KIAS, 8 seconds before the pull-up. It was 150 KIAS approximately 2 seconds after the apex. The cockpit field of view included the pilot's use of the left thrust lever. The pilot set constant thrust for the climb phase of the loop.

There were discrepancies between the left and right altimeter readings during the display. The left altimeter needle (intended to indicate hundreds of feet, and to complete one revolution every one thousand feet) lagged behind the right altimeter when climbing or descending, often appearing to become stuck temporarily before quickly catching up with the right altimeter. The resulting discrepancies between the two were greatest during dynamic flight. In roughly level flight the difference was approximately 200 ft or less. Over a six second period, during the downward half of one manoeuvre, the right altimeter needle 'lapped' the left altimeter needle, indicating a difference of more than 1,000 ft. The smoother motion of the right altimeter needle appeared better matched to the manoeuvres being flown than the more erratic motion of the left altimeter needle.

Image resolution and ambient lighting did not support a continuous or certain assessment of the presence of the STBY flag on the left altimeter. However, when lighting was favourable, the image suggested the STBY flag was in view. The results of the altimeter examination are detailed in Section 1.12.3.6.

The g-meter pointer, intended to indicate instantaneous acceleration, showed occasional sporadic movement, was at approximately 5.5 g for the majority of the flight, moved during the landing and indicated 4 g during the subsequent taxi.

1.11.7.4 Recent Jet Provost display flying

The pilot displayed a Jet Provost on both days of the weekend prior to the accident. Cockpit video recordings from both displays were provided. They captured the airspeed indicator and altimeter on both days but also suffered the same image contrast problems as the G-BXFI cockpit imagery when the aircraft was inverted. Two loops were flown as part of the display on both days. The indicated airspeeds and altitudes for each of the loops are given in Table 6. The wider tolerance of indicated altitude in the 'loop apex' column accounts for the reduced quality of the video due to poor image contrast when inverted.

Loop entry		Loop apex	
Indicated altitude (±50 ft)	Indicated airspeed (±5 KIAS)	Indicated altitude (±100 ft)	Indicated airspeed (±10 KIAS)
200	270	2,750	125
200	270	3,150	105
200	260	2,800	110
300	260	2,900	130

Table 6

Jet Provost loop parameters the weekend prior to the accident

1.11.7.5 Imagery from a previous flight

In a cockpit image recording from a previous flight in another Hunter part of a hand-drawn diagram of a sequence of manoeuvres is visible on the pilot's knee. This was identical to the one that would have been visible to the pilot during the accident flight (see Section 1.12.2.2 and Figure 17).

1.11.8 Engine performance

1.11.8.1 JPT and rpm

The engine manufacturer does not support the historical engine type fitted to the Hunter but provided analysis based on archived information and expert knowledge of jet engine performance in general. The performance information it provided related to a static engine under stable test conditions. It did not take into account performance losses associated with being installed in an aircraft, or dynamic performance.

The engine manufacturer reviewed the JPT indications captured by the cockpit action camera during the accident flight, the audio rpm figures, associated environmental conditions and basic flight parameters. The analysis was limited to periods when engine use was sufficiently stable to make valid comparisons with the documented values. This meant that the initial part of the flight could be assessed but engine performance during the dynamic manoeuvres from the start of the display could not. The engine manufacturer found that the engine appeared to be performing normally, with an appropriate relationship between rpm and JPT.

The same analysis was attempted for a flight from the year before. In that case the indicated JPTs were too low to be realistic (in any weather conditions), suggesting there was a problem with the indicated temperatures, making further analysis impossible.

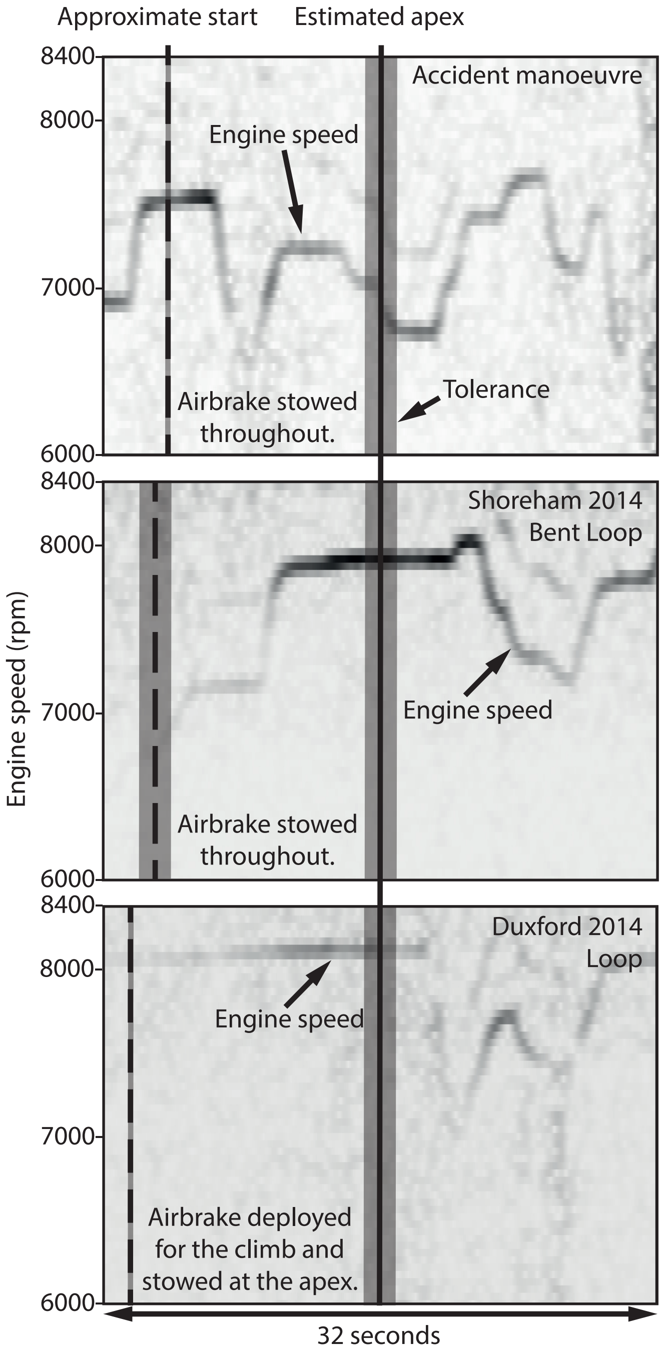
1.11.8.2 Engine speed during manoeuvres

Figure 15 shows the audio signature associated with engine speed for the accident manoeuvre, derived from audio spectrum analysis, and compares it with the two successful loop manoeuvres captured by the cockpit action cameras from previous displays flown by the same pilot.

The exact point at which a pull-up was initiated or an apex was reached was not always clearly defined. Complicating factors include the apex not necessarily coinciding exactly with the aircraft being level and inverted, indistinct horizons in the imagery, climbs initiated in a turn, key instruments being obscured and the changing geometry of the external imagery. Each frame in Figure 15 has an 'approximate start' and 'estimated apex' marker line, the thickness of which indicates the extent of this uncertainty. The resultant periods between the pull-up and the apex at the Shoreham 2014 and 2015 Airshows overlap. However, when the videos of the 'bent loop' manoeuvres were viewed side by side, it was observed that the first half of the Shoreham 2014 'bent loop' had a slightly higher pitch rate and was completed in a slightly shorter time than the first half of the Shoreham 2015 'bent loop'.

Engine speed during the loop at Duxford in 2014 was approximately the maximum allowable throughout the climb. The Shoreham 2014 manoeuvre was initiated with a low engine speed which then stepped up in two stages, levelling at slightly under 8,000 rpm for the last part of the climb. The climb for the accident manoeuvre was initiated with an engine rpm approximately half way between the initial engine rpms of the other two manoeuvres. The engine speed then reduced to below 7,000 rpm, recovered to and briefly held at 7,250 rpm, and then reduced further, passing below 7,000 rpm at the apex. At the apex of the accident manoeuvre, the engine speed was approximately 1,000 rpm lower than for the other two manoeuvres. A further distinction of the accident manoeuvre is that the engine speed increased during the descent whereas during the other two comparison manoeuvres the general trend was a reduction in engine speed.

To provide some context when comparing engine speeds during the manoeuvres it is helpful to note aircraft speeds and configurations. The entry airspeeds of the loops could not be established from the cockpit videos. Flap settings were similar, if not the same, during the accident manoeuvre and during the comparison manoeuvres at Shoreham and Duxford in 2014. The airbrake was deployed during the climb phase of the loop at Duxford. The aircraft airspeed and height at the apex of the accident manoeuvre was significantly lower than that for the Duxford manoeuvre (approximately 4,250 ft aal; no speed or height data was available for the Shoreham 2014 display).



Note: the relative darkness of the three audio signature lines has no significance

Figure 15

A comparison of engine speed during loop manoeuvres flown by the same pilot in the same aircraft with the same or similar flap settings during different displays

1.11.8.3 Engine speed indicator

Audio rpm was compared with the indicated rpm captured by the cockpit action camera during brief periods when the rpm indicator was in view. Indicated rpm consistently lagged audio rpm, being less than the audio rpm after speed increases and more than the audio rpm after speed decreases. Fifty-five sample points were taken from the three flying displays recorded on cockpit video. Of these, the maximum difference between the audio rpm and indicated engine speed was 226 rpm.

1.11.9 Recorded information from other aircraft and other flying displays

Radar data and video recordings indicated that instances of aerobatic manoeuvres occurring below 500 ft agl more than 1 km from the airfield, or flight below the heights specified in a display plan, were not limited to one aircraft, pilot or venue.

1.12 Wreckage and impact information

1.12.1 Accident site examination

The aircraft crashed on to the westbound carriageway of the A27, Shoreham Bypass, near its junction with Old Shoreham Road and Coombes Road, which is close to the northern perimeter of Shoreham Airport (see Figure 16). During the impact sequence the aircraft struck occupied vehicles and people around the road junction, traffic light stanchions, road signs and a crash barrier.

Ground marks and photographic evidence showed that the aircraft struck the road in a nose-high attitude on a heading of approximately 230°. The first ground contact was made approximately 50 m east of the road junction by the lower portion of the jetpipe fairing. During the impact sequence the external fuel tanks, which were made of phenolic resin reinforced with asbestos[26], fragmented and the right wing detached. Fuel and fuel vapour from the internal and external tanks was released and then ignited.

Just before the aircraft reached the Old Shoreham Road junction it came into contact with the crash barrier and trees beside the carriageway. The barrier deflected the path of the aircraft slightly to the right and away from other groups of people congregated around the junction.

The aircraft continued across the junction and passed through a number of small trees and down a bank into a shallow overgrown depression to the south of the A27. It came to rest in four main pieces which were close together, approximately 243 m from the initial point of ground contact, as shown in Figure 16.

26 The presence of asbestos was not identified until a week after the accident.

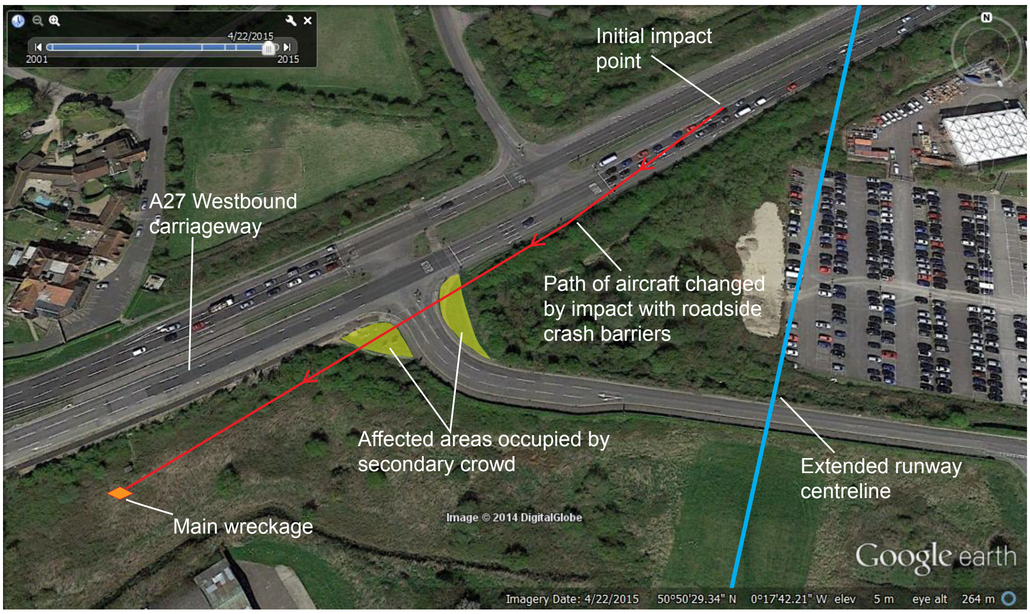


Figure 16

Illustration of accident site location (image not from the day of accident)

1.12.2 Aircraft on-site examination

1.12.2.1 Structure

During the impact sequence the aircraft broke into four large sections. The main items of wreckage comprised the forward fuselage and cockpit; the centre fuselage, engine and left wing; the rear fuselage and tail cone; and the right wing which was found inverted close to the centre fuselage. The nose structure forward of the cockpit was destroyed.

The section comprising the centre fuselage, engine and left wing had been subjected to a substantial post-crash fire and was partially submerged in a pool of unburnt jet fuel and firefighting media. The other sections were largely unaffected by the post-crash fire.

1.12.2.2 Cockpit

Photographic evidence of the final moments of the accident sequence showed that the cockpit canopy separated from the aircraft soon after it struck the road. The canopy was found in trees at the top of the embankment, close to the cockpit section. The canopy jettison jacks had extended on each side of the cockpit sills. Examination of the canopy frame showed indentations coincident with the location of the canopy jacks, indicating they had operated under gas pressure. The canopy jettison handle had not been operated.

The pilot and his seat were thrown clear of the cockpit during the latter stages of the impact sequence. Emergency first responders reported that the pilot was found on the ground, close to the left side of the cockpit, wearing his combined parachute and restraint harness. A personal survival pack was still attached to the pilot's harness and had not been opened.

The left cockpit sidewall had been breached by a side-on impact. The left lower side of the forward fuselage had sustained substantial disruption during impact. The pattern of damage suggested that it was caused, at least in part, by the aircraft sliding along the roadside crash barrier. There was substantial disruption to the cockpit floor structure just aft of the bottom attachment point of the left ejection seat.

Documentation

Documentation was retrieved from the pockets of the pilot's anti-g trousers and flying suit including hand-written notes, a number of checklists and a copy of one of the display maps for the 2015 Shoreham Airshow. Documentation in the transparent knee-pockets, which would have been visible to the pilot during the flight, included a checklist and a hand-drawn diagram. This diagram was not specific to the display routine performed by the pilot at the 2015 Shoreham Airshow; video evidence indicated this same diagram had been visible in the pilot's knee-pocket during a previous flight (see Section 1.11.7.5).

The pilot had annotated one of the display maps for the 2015 Shoreham Airshow (see Figure 17) with the sequence of manoeuvres he intended to fly during the display, and other reference information such as relevant frequencies; this was found folded in a separate pocket, and would not have been visible to the pilot during the flight.

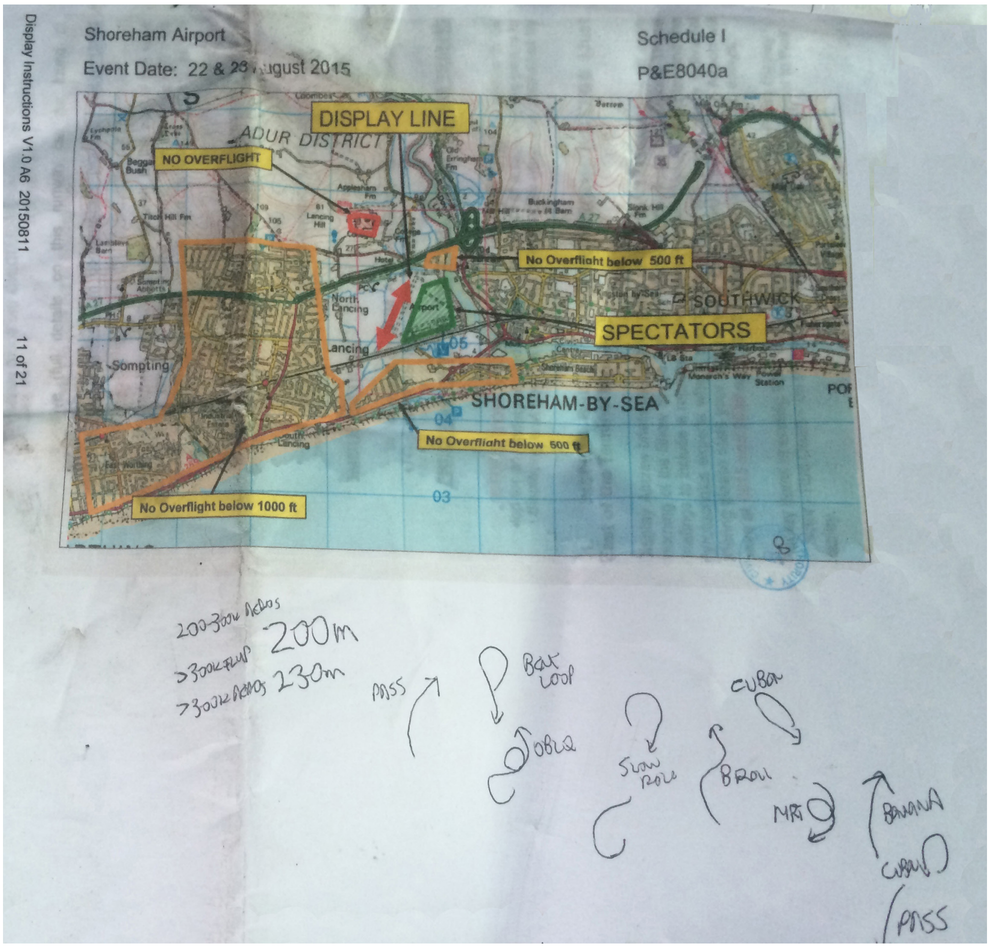


Figure 17

Annotated display map from pilot's pocket.
The image has been edited to remove damage sustained in the accident

1.12.2.3 Ejection seats

Pilot's (left) seat

The pilot's seat was lying face-down on the ground, underneath the main cockpit wreckage and was substantially damaged.

During operations to make the ejection seats safe at the accident site, it was found that the left seat primary ejection gun cartridge, drogue gun cartridge and guillotine cartridge had fired, but the two secondary ejection gun cartridges had not. The harness release plunger was extended and the scissor-shackle was released, indicating that the Barostatic Time Release Unit (BTRU) had operated. The canopy jettison cartridge had also fired.

The SPFH was stowed within its housing, indicating that it had not been pulled. The face-screen handle had been fully removed from, and was lying close to, its housing in the ejection seat's drogue container.

The ejection gun had suffered major structural damage at its base. The bottom fitting remained bolted to the cockpit floor but had fractured such that the ejection gun assembly had separated from the bottom fitting and was unrestrained. The bottom portion of both guide rails exhibited damage consistent with having sustained a sideways impact.

The ejection gun tubes had not fully extended. The circular bracket attaching the ejection gun to the top fitting had sheared on one side. The spring-loaded plunger had over-ridden the top-latch window and there were a number of damage marks around the top-latch window.

The controller and main drogues had been extracted from their housing, but had not inflated and were entangled with cockpit wreckage and tree debris. The drogue-to-parachute withdrawal line had been severed by the ejection seat guillotine. There was no evidence that the manual separation handle had been pulled. The main parachute had remained within its container, but the auxiliary parachute had been fully extracted.

Right seat

The unoccupied right ejection seat remained inside the cockpit. The circular bracket attaching the ejection gun to the top fitting was sheared on both sides, leaving the seat and ejection gun free to tilt forward, pivoting about the ejection gun bottom fitting. The seat was also free to slide up the guide rails as the spring-loaded plunger had been forced upwards, fracturing the upper part of the top-latch window.

The drogue gun cartridge and guillotine cartridge had fired but the primary and secondary ejection gun cartridges had not. The BTRU had operated and released the parachute locks. The parachute withdrawal line had been severed by the guillotine.

The controller drogue had been ejected by the drogue gun, and the main drogue was partially withdrawn from its container. The main parachute remained packed within its parachute container.

1.12.3 Further examination

1.12.3.1 Flying controls

The airframe was severely damaged but, to the extent possible, examination of the primary flying controls did not reveal any pre-accident defects. The three hydraulic actuators (two aileron and one elevator) were taken to the original manufacturer, which was able to assist in their disassembly and inspection. The units were determined to have been in good condition prior to the accident and no defects were found that would prevent their normal operation.

The variable incidence tailplane had been subjected to large impact forces. The position of its electric actuator was determined, from inspection of photographs and video evidence, to be in a normal neutral position immediately prior to the accident. This is consistent with the normal operating procedure for this type of flying where the tailplane is used only for trimming and not in its elevator follow-up trim mode.

1.12.3.2 Hydraulic system

It was not possible to check the operation of the hydraulic system due to disruption of the aircraft. The hydraulic pump was disassembled and found to be full of fluid and in good condition with no defects. There was no sign of hydraulic fluid staining on the airframe that could indicate a leak. Limited video evidence from the cockpit action camera did not show any anomalies in the aircraft’s response to control inputs.

1.12.3.3 Electrical system

It was not possible to test the electrical system. There were no indications of an electrical system failure on the cockpit video.

1.12.3.4 Pitot-static system

It was not possible to test or check the integrity of the aircraft’s pitot and static systems due to the extensive structural disruption resulting from the accident, but the altimeters and ASIs were removed from the cockpit and bench tested.

1.12.3.5 Airspeed indicators

Both ASIs were removed from the cockpit for testing. The instrument glass on the left ASI was broken as a result of the accident, but the instrument casing was otherwise intact. Computer tomography (CT) scanning determined that there was no evidence of damage to the internal mechanisms of either unit. Despite the damage to the instrument glass, the left ASI functioned normally and was determined to be within the required calibration. The right ASI functioned normally but was marginally outside of the required calibration. The results are shown in Table 7.

Speed Range (kt)	80-300	310-400	410-500	510-600	610-750
Permitted tolerance (kt)	± 2	± 4	± 5	± 6	± 7
Right ASI Maximum deviation (kt)	+5.0	+6.5	+5.5	+4.0	Not tested
Left ASI Maximum deviation (kt)	+1.0	+1.0	-2.0	-2.0	Not tested

Table 7

Airspeed indicator ranging test results

1.12.3.6 Altimeters

The altimeters had not suffered any obvious external damage during the impact and CT scans showed no evidence of damage to the internal mechanisms of either unit. However, the power failure flag on the Mk 30B appeared to be stuck above the height counter drum. The STBY flag was visible on the Mk 29B altimeter, but it was not possible to determine which mode had been selected during the accident flight as it would have reverted automatically to standby mode upon disruption to the electrical power supply during the impact.

As found in the cockpit, the barometric pressure setting on the left altimeter was 1014 mb and on the right altimeter was between 1016 and 1017 mb.

The altimeters were function-tested at a specialist facility in accordance with the original manufacturer's standard test schedule. Each altimeter was tested in isolation and then both altimeters were connected together, in order to replicate their installed configuration. The build history for each altimeter was also reviewed. The testing is briefly described below, with additional detail presented in Appendix A.

Mk 29B testing

The Mk 29B failed the manufacturer's test because it exhibited an offset of approximately -100 ft between the actual altitude and the displayed value across its entire range, such that it would read approximately 100 ft lower than the actual aircraft altitude. The manufacturer stated that this finding suggested the altimeter may have been calibrated incorrectly at build or when last serviced, or that the offset could be attributed to minor slippage within the altimeter gear train due to accident impact forces.

The Mk 29B also failed the testing due to excessive friction identified within the mechanical components of the gear train and height counter drum. This was consistent with expected component wear in an altimeter of this age, which may not have been serviced for many years. Excessive friction could cause lag between the measured and displayed altitude. This effect was particularly evident on the Mk 29B when it was tested in standby mode and more so with its vibrator motor switched off.

Mk 30B testing

The altitude displayed by the Mk 30B was within the permissible tolerances and the encoded output correctly corresponded to the displayed altitude. However the Mk 30B failed the test because there was no signal output from its synchro-transmitter. The effect of this would be that, when the Mk 29B was operating in servo mode, the Mk 30B altimeter would not transmit the required electrical signal to the Mk 29B.

Mk 29B and Mk 30B combined testing

The Mk 29B and Mk 30B were connected together using the altimeter wiring loom which had been extracted from the aircraft, in order to observe the effects of the absent synchro-transmitter signal. When in servo mode, the Mk 29B did not follow the Mk 30B accurately, instead displaying lower altitudes; the under-read was more pronounced when altitude was increasing than when it was decreasing. This hysteresis effect was probably associated with the previously identified friction within the internal gearing of the Mk 29B. Furthermore, its vibrator motor did not operate, and the pointer and height counter exhibited 'stickiness' and did not rotate smoothly.

This test was repeated using workshop test cables to connect the altimeters. The same anomalies were observed, ruling out any faults within the aircraft altimeter wiring loom.

The Mk 29B was also connected to a fully serviceable Mk 30 unit, which was similar to the Mk 30B. No anomalies were noted, other than the previously observed -100 ft offset in the Mk 29B, indicating that the Mk 29B functioned correctly in servo mode when it received a valid signal from the master altimeter.

Disassembly of the Mk 30B and the synchro-transmitter

Disassembly of the Mk 30B and further testing identified an open circuit across the rotor windings of the synchro-transmitter. It also confirmed that the power failure flag had come off its pivots, probably as a result of the accident impact.

Disassembly of the synchro-transmitter, and examination under a digital stacking microscope, identified that one of the input wires to the rotor winding was broken, which could account for the open circuit. This damage was probably not accident related, but there was no way to determine how long this condition had existed.

Mk 30B S/N 993 testing

The Mk 30B altimeter S/N 993, previously installed in G-BXFI (see Sections 1.6.14.2 and 1.11.7.3), was obtained by the investigation for comparative testing. S/N 993 was tested in isolation and, when connected to the Mk 29B from G-BXFI, no defects were observed.

1.12.3.7 Accelerometer (g-meter)

Cockpit video evidence indicated that the g-meter was not working during the accident flight or during a number of previous flights (see Section 1.11.7). There were no defects relating to the g-meter in the technical log and the maintenance organisation informed the AAIB that it was not aware of any.

Post-accident examination of the g-meter indicated that the internal mechanism was loose, and it was therefore not possible to test the unit. Disassembly of the unit revealed that the control cord which centres the weight was broken and the weight was free to move unrestrained on the guide shafts. The lower pulley, around which the cord is normally routed, was loose, as was the grub screw which holds it in place.

It was not possible to determine whether the cord broke as a result of impact forces, or whether this damage existed prior to the accident. It is unlikely that the grub screw and lower pulley were loose because of the impact, but the loose pulley may have altered the tension in the control cord and the degree to which the weight could move. This could explain the unserviceability of the g-meter prior to the accident.

1.12.3.8 RPM indicator and tacho-generator

The rpm indicator appeared to be undamaged, however, the needle indicated 200 rpm when unpowered. The rpm indicator and tacho-generator were connected electrically and tested by the AAIB. The testing indicated that both units functioned as expected and the correct relationship was observed between tacho-generator input and the displayed rpm. However, the rpm indicator read on average 200 rpm higher than the actual value. In addition some hysteresis was evident, but not to the same extent observed in the cockpit video recording of the accident flight. At the completion of the testing, the rpm indicator needle remained at +200 rpm rather than returning to zero.

It was concluded that the 200 rpm offset was most likely due to accident damage in the internal mechanism of the rpm indicator. Section 1.11.8.3 provides information about the performance of this instrument based on cockpit video recordings.

1.12.3.9 Anti-g system

It was not possible to test the anti-g system due to accident damage. The air bottles and associated pipework were damaged and it was not possible to determine the air pressure in the system at the time of impact. A distinctive noise, recorded on one of the action cameras after the aircraft had come to rest, was similar to that sometimes heard when air from the anti-g bottle leaks across the shut-off valve, indicating that the air bottles were probably pressurised at the time of the accident.

The maintenance organisation stated that the air bottles were fully charged prior to the accident flight. Examination revealed that the shut-off valve was not in the fully ON position but witness marks indicated that this was probably the result of impact damage. The filter was clean. The pressure-reducing valve was tested and found to leak.

Examination of the disassembled components confirmed that the valve bellows had failed due to the presence of a 250° circumferential crack. Microscopic examination of the fracture surfaces had the characteristics of a failure due to overload consistent with the forces experienced during the impact. There was no evidence of corrosion or fatigue on the fracture surfaces. The anti-g valve was tested in a centrifuge and found to operate normally. The hose connecting the anti-g trousers to the aircraft appeared to be in poor condition but as it had been damaged during the impact it was not possible to determine its integrity beforehand.

1.12.3.10 Engine examination

The throttle and high pressure fuel shut-off valve (HPSOV) cam boxes, which convert the linear movement of the pilot's controls into a rotary motion to operate the FCU fuel metering valve and HPSOV in the FCU, were removed from the fuselage and examined using CT scanning. No defects were identified within either unit.

It was not possible to test the engine exhaust gas thermometer because of extensive damage to the thermocouples and associated wiring.

A partial disassembly of the engine was carried out by the AAIB with the assistance of the engine manufacturer and an organisation familiar with maintaining the Avon engine. The report of the manufacturer's strip examination is included at Appendix E.

Examination of the compressor confirmed that all the stators and blades were present. Accident damage was evident on all compressor stages but was particularly severe on the first five stages. Vegetation was found within the compressor case bleed air galleries. Five of the eight combustion chambers were removed and examined. All were in good condition with no evidence of liner cracking or uneven fuel spray patternation. The turbine blades and nozzle guide vanes did not appear damaged.

Inspection of the variable inlet guide vane actuator confirmed that it was within the normal operating range and examination of the engine's Fuel Dip Unit system confirmed that the unit had been disabled. Disassembly of the BVCU confirmed that there was no evidence of a pre-impact defect which would have affected its normal operation.

The engine controls were removed and inspected with no abnormalities being identified. The fuel pump, FCU, BPC and ACU were disassembled at a specialist facility, by the manufacturer of the units, under AAIB supervision. Examination of the FCU components confirmed the presence of wear associated with normal operation. There was no evidence of pre-accident defects within the FCU, the ACU and BPC. There was no evidence of pre-existing defects in the swash plate pumps of the fuel pump. The metallic components of the fuel pump hydro-mechanical governor showed evidence of normal operational wear. However, the governor diaphragm showed evidence of deterioration. The governor diaphragm, together with the diaphragms removed from the ACU and BPC, were subject to detailed laboratory analysis.

The laboratory examination, Appendix F, confirmed that both ACU diaphragms were intact but showed evidence of the effects of ageing. The BPC diaphragm showed no evidence of distress or ageing. The fuel pump governor diaphragm, which was made from two plies of a Polychloroprene rubber-proofed textile, showed significant signs of distress. The laboratory report made the following findings:

'4.1.2 The base polymer used for the rubber compound, Polychloroprene, has a known limited life in aviation kerosene.

4.1.3 However, when managed correctly any equipment containing a diaphragm manufactured from a Polychloroprene will not proceed to a point at which the resistance of the rubber composition of the kerosene has been exceeded i.e. aged

4.1.4 The 'Mud-Cracking' seen across the entire surface of the working convolution was a combined result of calendar life and exposure to kerosene.

4.1.5 The appearance would suggest there have been significant periods of non-operation where fuel will slowly degrade to form active chemical species (peroxides) that will then go on to attack the rubber.

4.1.6 The appearance of a 'Tide-Mark' across the convolution was also evidence to suggest the diaphragm has been subject to periods of inactivity and where the fuel has been allowed to drain away.

4.1.7 Draining the fuel away from the diaphragm, whilst reducing the exposure to degrading species, also results in the rubber loosing flexibility and will crack because the fuel can no longer act as a plasticiser for the rubber.

...

4.1.9 The interchange of plasticiser, added to rubber during manufacture, with kerosene when installed, is a well understood phenomenon. It is the reason why equipment containing diaphragms and rubber seals is not left static without constant exposure either to kerosene or inhibiting fluid, when not in use.

…

4.1.13 The degradation of the rubber on both faces of the convolution, due to the effects of age, loss of flexibility and chemical interaction with fuel have resulted in a diaphragm that has exceeded the known predictable functional capability of the design.'

The condition of the hydro-mechanical governor diaphragm indicated that it had suffered from the combined effects of calendar ageing, 'drying out' and chemical attack due to prolonged periods of inactivity in the presence of aviation kerosene. The extent of this degradation meant it was not in an airworthy condition. The CAA-approved manual for the Rolls-Royce Avon 122 engine (AP 102C-1512 to 1517) details the requirements for engine storage or periods of non-operation:

'Up to 1 month	*Apply anti-corrosion fluid to compressor. Fit engine covers and blanks. Spray engine with lanolin resin temporary rust prevention.*
Up to 6 months	*As up to 1 month. In addition, ground run every 30 days and repeat application of anti-corrosion inhibiting fluid to compressor. If the engine is not to be ground run, drain engine oil, inhibit fuel system, apply anti-corrosion paper. Grease the control and inlet guide vane ram linkages.'*

The maintenance organisation indicated that it was normal practice to keep the aircraft fuel system as full as possible during maintenance to minimise moisture build up and microbiological growth; it was unaware of the possibility of degradation of aviation kerosene into compounds which would actively attack components similar to the governor diaphragm. It was not its normal practice to inhibit the engine fuel system but it indicated that, if downtime was prolonged, engine runs would be carried out.

Examination of the aircraft records from July 2012 showed that there were five separate occasions where the aircraft did not operate for a period of more than 30 days. During these periods engine runs were completed towards the end of the maintenance input but no evidence was found of engine runs being completed at 30 day intervals.

Between August 2012 and the date of the accident, the periods during which G-BXFI's engine had been inoperative for more than 30 days amounted to approximately 43% of the time. Records of the aircraft's utilisation prior to August 2012 showed that this level of inactivity had also been prevalent prior to August 2012.

Based on the known utilisation of other civil registered Hawker Hunters, the periods of inactivity identified in G-BXFI's records are considered to be typical. The preservation of engine fuel systems during prolonged periods of non-operation was discussed by the AAIB with a number of other organisations involved in the operation of historic jet aircraft, including the Hawker Hunter. They considered that the reason for inhibiting the engine fuel system was to prevent water contamination and were also unaware of the effects of fuel degradation. The organisations also confirmed that it was not their normal practice to inhibit engine fuel systems during prolonged periods of non-operation.

The fuel control systems of other ex-military gas turbine powered fixed and rotary-winged aircraft may contain components, made from similar materials, whose condition cannot be monitored without specialist facilities. Accordingly, the AAIB presented the findings of the associated laboratory report to the CAA.

As a result the CAA published MPD 2016-001 on 07 October 2016. Appendix G. This MPD requires:

> *'For any applicable turbine engine with calendar time greater than 20 years since last overhaul:*
>
> *Within 1 month or 10 flying hours from the effective date of this MPD, whichever limit is reached first:*
>
> > *Examine the engine records subsequent to the release from military service and record evidence found of:*
> >
> > *a) Regular running of the engine, shown to be at intervals and to methods in accordance with manufacturer's instructions and*
> >
> > *b) Inhibition of the engine fuel system in accordance with manufacturer's instructions after any period of inactivity specified in the relevant operating manuals.'*

For engines which do not meet these requirements a failure analysis must be carried out by the operator/maintenance organisation to determine the severity of a failure of any elastomeric components within the engine's fuel system. The MPD states:

> *'Note: Such a failure analysis is considered an Alternative Means of Compliance (AMOC) and requires separate CAA acceptance. The authors of the analysis and the analysis method to be used are to be acceptable to the CAA'*

1.12.3.11 Fuel system

It was not possible to test the fuel system due to accident damage. Some fuel was recovered from the wing tanks but it was contaminated with firefighting media and debris resulting from the accident so could not be usefully tested. The aircraft had been refuelled to full prior to departure and the extent of the post-accident fire indicated that there was a considerable quantity on board. Examination of the engine fuel pump assembly did not show any signs of cavitation that could indicate a restriction in fuel supply.

A number of photographs taken by witnesses showed a plume of vapour emanating from a point close to underwing fuel tank on the right wing. The exact source could not be seen. Examination of these photographs indicate that the vapour plume is likely to be fuel vapour occasionally venting from a fuel system vent in this area. A similar vapour plume can be seen in some photographs taken of the same aircraft during its display at the 2014 Shoreham Airshow, and it is not considered relevant to the accident.

1.13 Medical and pathological information

1.13.1 Pilot

The pilot was not aware of any pre-existing medical condition and toxicology did not reveal the presence of drugs or alcohol in his system that may have contributed to the accident. He received serious injuries as result of the accident.

He was treated by a doctor and nurse at the scene. He was described by the doctor as "fully aware of what was going on around him and not confused in any way". The doctor recalled that the pilot, when asked if he felt unwell before the crash, replied "yes". The investigation could not establish if the pilot understood the intent of this exchange, in what way he might have felt unwell, or if this was his answer. Analysis of the associated audio recording was inconclusive (see Section 1.11.6).

1.13.2 Third parties

Eleven people received fatal injuries as a result of the accident.

Thirteen people including the pilot are known to have received non-fatal injuries, and were treated by the ambulance service, local volunteer services and the display organiser's on-site medical response contractors.

The AAIB was unable to determine the number of individuals receiving other injuries, including non-physical injuries, because there was no central record

1.14 Fire

There was a significant post-impact fuel fire caused by the disruption of the aircraft fuel tanks and fuel system. The released fuel and fuel vapour ignited and initially produced a large fireball, followed by a sustained pooled fuel fire around the wreckage.

1.15 Survival aspects

1.15.1 Fire and rescue services

Significant medical and fire-rescue resources were available, including those provided by the display organiser, pre-deployed local authority services and the normal emergency services both on the airfield and in the local community.

A local authority Fire and Rescue Service pump ladder vehicle that had been pre-positioned approximately 220 m from the A27 / Old Shoreham Road junction was at the accident site within 90 seconds and commenced firefighting operations immediately.

The injuries sustained by those on the ground were not survivable. No additional emergency response provisions would have altered the outcome.

1.15.2 Pilot's helmet

The pilot was wearing a Helmet Integrated Systems Ltd Mk 4A/4 helmet, a type still in use with the UK military. Several areas of damage on the crown and rear of the helmet outer shell were evident, with corresponding areas of damage to the underlying energy-attenuating foam. The damage pattern indicated the helmet had been subjected to multiple discrete impacts, consistent with the pilot having sustained major head impacts during the accident. Nevertheless the energy attenuation afforded by the helmet ensured that his head injuries were not fatal.

1.15.3 Aircrew equipment assemblies (AEA)

The pilot was wearing a Mk 15T tropical flying coverall, Mk 2A anti-g trousers, a Mk 30 life preserver, and leather gloves. The flying coverall and anti-g trousers had been cut in several places, consistent with removal by the emergency services, so it was not possible to test the functioning of the bladder system in them.

Despite the extensive post-crash fire there was no fire in the cockpit, or the area in which the pilot was found. Accordingly no further assessment was made regarding the protective qualities of the flying overall and gloves.

The pilot was also wearing a P18/P19 oxygen mask. The protective exo-skeleton was missing. The face piece contained several tears and the emergency oxygen hose was cut. This damage probably occurred during the accident.

No maintenance documentation was provided relating to the pilot's AEA, so it was not possible to determine if it was maintained.

1.15.4 Survival equipment

The Mk 4HA ejection seats fitted to G-BXFI were equipped with a Mk 41A emergency escape parachute assembly (EEPA), Mk 6 quick release fitting (QRF) and a personal survival pack (PSP).

The EEPAs and PSPs were generally in good condition and packed correctly. It was considered likely that if an ejection had occurred, within the safe ejection envelope, the parachute canopy and PSP would have operated as designed. The EEPAs and QRFs had last been maintained in March 2015 and the PSPs in February 2015. However, no maintenance history or modification records were available. A number of EEPA components had exceeded their recommended lives. The absence of records meant it was not possible to determine when they had been installed in G-BXFI.

1.16 Tests and research

1.16.1 Flight trials

The AAIB commissioned a series of three flight trials using a Hunter flown by an experienced Test Pilot (TP), who also acted as an advisor to the investigation. The full trial report is included in Appendix H[27]. The aim was to gain an understanding of the accident manoeuvre, with four objectives:

1. To determine if, having reached the apex of the accident manoeuvre, it would have been possible to fly an alternative 'escape' manoeuvre such that a collision with the ground could be avoided.

2. To determine if, having reached the apex of the manoeuvre, it was possible to have continued the pull through manoeuvre, as attempted, and avoid a collision with the ground.

3. To find out what influenced the speed and height achieved at the apex of the accident manoeuvre.

27 Where Appendix H refers to a 'bent loop' manoeuvre, this is the manoeuvre as understood by the TP and not necessarily as intended by the pilot of G-BXFI at the time of the accident.

4. To determine if a 'bent loop' manoeuvre could be flown safely if entered with a different combination of airspeed, pull-up technique and power from those used in the accident manoeuvre.

The TP is a qualified military test pilot and tutor at the UK Empire Test Pilots' school. He has approximately 10,000 hours flying experience on over 150 aircraft types. He has approximately 1,000 hours experience on the Hawker Hunter, and was current on the type at the time of the flight trials. He was also a UK DA holder and DAE.

The aircraft used was a single-seat Hawker Hunter F Mk 58. Allowances were made for the differences between this aircraft and the two-seat Hawker Hunter T Mk 7 accident aircraft. For example, the engine manufacturer provided engine speeds for use in the trials aircraft that would produce thrust equivalent to that of the Mk 122 fitted to the accident aircraft. The only significant difference in construction is that the nose and canopy of the two-seat T Mk 7 is wider, potentially developing more lift than the single-seat canopy and increasing instantaneous turn performance. Historical trial data was available for the instantaneous turn performance of the T Mk 7, and comparative data was gathered for the F Mk 58. Analysis of this data indicated that there was not a significant difference in maximum instantaneous turn performance between a T Mk 7 and F Mk 58 and that the lift-related data gathered in the F Mk 58 was representative of the T Mk 7.

Two data gathering sorties were flown on 19 October 2015 totalling 1 hour and 25 minutes. Following analysis of the data from these sorties and other information gathered during the course of the investigation, a third 55 minute sortie was flown on 4 December 2015 to gather additional data.

Based on the data gathered during the sorties flown, the TP concluded the following:

1. *'From the apex height and airspeed achieved in the accident manoeuvre, and for up to at least four seconds after passing the apex, it would have been possible for an appropriately trained pilot to fly a straightforward escape manoeuvre in G-BXFI which would have prevented impact with the ground by rolling the aircraft through 180° back to erect flight and then pulling out of the dive to regain level flight.*

2. *The measured height loss during a representative pull through from the apex of a loop at the airspeed, all up mass and density altitude of the accident manoeuvre was between*

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2,700 and 2,850 ft, and if altimeter reading resolution and instrument errors were considered the range would increase to between 2,600 and 2,950 ft. The height loss appeared to be insensitive to whether 1 or 2 notches of flap were selected and to the power setting.

3. The 'bent' loop tests indicated that the apex height and airspeed of the accident manoeuvre was consistent with a maximum performance pull-up from 300 KIAS with significantly less than full thrust and with a 45-90° bend initiated approximately five seconds after pull-up. They also showed that the apex height for a 'bent' loop was 300 to 400 ft less than for a straight loop with all other parameters constant.

4, A 90° 'bent' loop entered at 350 KIAS with full T Mk 7 thrust was, for an appropriately trained pilot, a safe and straightforward manoeuvre to fly.'

These flight trials also demonstrated that entering a straight loop at a speed of 300 KIAS from 200 ft agl, and T7 equivalent maximum thrust, the aircraft achieved apex heights between 3,400 ft and 3,800 ft agl while conducting looping manoeuvres, or a height gain of between 3,200 ft and 3,600 ft. Conducing bent loops with the same entry conditions resulted in height gain of between 2,800 ft and 3,200 ft.

1.16.2 Radar Mode C validation

There are two sets of criteria required by radar systems to validate Mode C data, one for altitude change since the last sweep and another for quality of data pulses associated with data transferred during a sweep. The maximum allowed altitude rate before a problem is flagged is 15,000 ft/min; given the rotation rate of the Pease Pottage radar, this translates to a maximum allowable change between Pease Pottage sweeps of 1,600 ft. This limitation would only account for one of the 'Not-validated' returns. The other 'Not-validated' returns are therefore associated with the quality of pulses received during the sweep.

For each detected aircraft a data point is recorded once per sweep by a radar system. However, the rotating radar head actually carries out the detection process multiple times for each aircraft as it sweeps round, generating multiple positions and Mode C responses. The system then uses these to generate a single record pertinent to the sweep, marking the Mode C as 'validated' or 'Not-validated' in accordance with criteria set by the radar system manufacturer. There are no standards set across the manufacturers for these validation criteria. The multiple returns generated by each sweep are not recorded so it is not possible to determine the reason for some of the Mode C data not being validated.

Each of the multiple aircraft transponder responses is made of multiple pulses. Ideally, the radar head would receive two replies with identical information made from good quality pulses. The radar builds a confidence level based on typically more than a hundred pulses measured in three different ways. Every radar response sent by an aircraft is subject to degradation from many causes including interference due to responses from other aircraft, the return signal coming via multiple paths and being at the edge of radar coverage. The radar returns from an aircraft carrying out aerobatic manoeuvres, flying relatively close to the ground compared to normal commercial aircraft, and flying in the south-east of England with its relatively high aircraft density, are likely to suffer from all of these issues to varying extents.

The original returns used to generate the once-per-sweep data were not recorded, therefore it is not possible to state the exact cause for some of the data being marked as 'Not-validated'.

During the flight trials there was good correlation between the recorded path of the aircraft and recorded Mode C altitudes despite the majority of the Mode C values being reported as 'Not-validated'.

Given the effects that flying display manoeuvres can have on the quality of radar data pulses and the correlation between the radar recorded path and the other evidence, it is more likely than not that despite the radar data not being validated, it was in fact appropriate.

1.16.3 Radar detection of peak altitudes

The looping manoeuvres flown during the flight trials were recorded by a radar with a refresh rate of approximately 8 s. A comparison was made between the peak altitudes achieved (as reported by the TP) and the peak altitudes recorded by the radar (after correcting for ambient pressure conditions). Despite the radar returns being 8 s apart and rarely coinciding with the peak of the manoeuvre, the nearest radar return (in time) was always within 550 ft of the apex height reported by the TP, within 260 ft for the majority of loops (88%) and on average was within 175 ft.

The data shows that the loops with larger differences between the apex altitude and highest recorded radar altitude were associated with the smaller differences between the recorded radar altitudes either side of the apex. So, if the radar returns either side of the apex are similar, a larger difference between these and the aircraft peak altitude can be expected.

1.17 Organisational and management information

1.17.1 Operation of ex-military aircraft on the UK civil register

Ex-military aircraft on the UK civil register are required to operate in accordance with CAP 632 '*Operation of Permit-to-Fly ex-military aircraft on the UK register.*'

1.17.2 Record of flight training

G-BXFI was purchased by the operator in July 2012. A Chief Pilot was appointed who also carried out pilot training. As part of the CAP 632 structure, the Chief Pilot had produced a seven page Organisational Control Manual (OCM), which set out the company operating policy and procedures.

At the time of setting up the operation, the operator's two pilots held valid ATREs and DAs for the Hawker Hunter, obtained with the previous operator of the aircraft. The training syllabus was documented in that operator's OCM but the training records had not been carried over to the new organisation, and were not required to be. The accident pilot had, however, retained copies of his training records from the previous company and made them available to the investigation. They did not contain a detailed description of what was covered on each training flight but both the Chief Pilot and the accident pilot provided a general overview of their content, and the summaries of the air exercises were available. The CAA provided copies of both pilot's ATRE and DA initial issue and renewal forms.

The CAA carried out an audit of the operator on 3 January 2013. The Audit Report Form stated:

> *'A new OCM, one pilot one aircraft hangered at A8-20* [refers to approved maintenance organisation].
>
> *A good system in place for record keeping run by the Chief Pilot who is a current serving RAF officer.*
>
> *Recommended next audit 12 months and then if no Observations 18 months.'*

On 7 January 2014, another audit was carried out and the FSO commented as follows:

> *'A reasonably good operation run by an ex RAF Sqn Ldr.*
>
> *There are elements within the operation that could be improved; Notably the requirement to have a Dual Check 'who checks the checker' this has been embraced and a log of recurrent training including EKQ[28] is going to be embodied within the OCM in the form of an Annex.*
>
> *Level 2 finding:*
>
> *The turn round schedule as referred to in the approval from the A8-20 not in existence.'*

The observation by the FSO that there needed to be a dual check carried out for each pilot was actioned and a flight was carried out on 24 March 2014 when the pilots carried out a mutual check. This was not recorded in the training records for the operator but, according to the CAA, it should have been.

The accident pilot had submitted a proposed Training Record form to the Chief Pilot and had completed one for the dual check he carried out on the Chief Pilot, but this was not filed. Training records are the operator's documented evidence of what training has been carried out. They can also be an important element of an AAIB investigation.

There were no CAA audits of the operator between 7 January 2014 and the accident.

1.17.3 Safety management systems

1.17.3.1 Introduction

CAP 795 – *'Safety Management Systems (SMS) guidance for organisations'*, published by the CAA, states:

> *'SMS is a proactive and integrated approach to managing safety including the necessary organisational structures, accountabilities, policies and procedures. It is more than a manual and a set of procedures and requires safety management to be integrated into the day to day activities of the organisation. It requires the development of an organisational culture that reflects the safety policy and objectives.*

28 Essential knowledge quiz.

> *At the core of the SMS is a formal risk management process that identifies hazards and assesses and mitigates risk. It is important to recognise that even with mitigations in place, some residual risk will remain and an effective SMS will enable organisations to manage this.'*

1.17.3.2 International Civil Aviation Organisation

Section 3.1 of Annex 19 to the Chicago Convention requires States to have a State Safety Programme (SSP) which should set out:

> *'a. State safety policy and objectives*
>
> *b. State safety risk management*
>
> *c. State safety assurance*
>
> *d. State safety promotion'*

And requires that:

> *'The acceptable level of safety performance to be achieved shall be established by the State. The SSP established by the State is commensurate with the size and complexity of its aviation activities.'*

The UK has an extensive flying display community which ranks among the most active in the world.

The CAA stated that the duty contained in International Civil Aviation Organisation (ICAO) Annex 19, which places an obligation on specific organisations to implement a SMS, does not apply to organisations that are responsible for the operation of civil air displays in the UK.

1.17.3.3 CAP 632 – *'Operation of 'Permit-to-Fly' ex-military aircraft on the UK register'*

CAP 632 states in paragraph 3.4 'Safety Management':

> *'High safety standards are achieved not by the imposition of rules and regulations but through the development of a positive safety culture…The development of such a culture can be achieved in a number of ways but that recommended by the CAA is the adoption of a Safety Management System (SMS).'*

And:

> *'The CAA website contains guidance for SMS including specific guidance for small non-complex organisations… includes templates for SMS manual contents, safety report forms and hazard logs.'*

CAP 632 includes an SMS evaluation tool.

CAP 1059 – '*Safety Management Systems: Guidance for small, non-complex organisations*' published in June 2013 states:

> *'In recent years our understanding of how accidents and incidents happen has improved. More emphasis is now placed on the causal factors involved and the organisational factors that contribute to errors being made. Organisational factors include how an organisation operates, how it sets out its procedures, how it trains its staff and what level of importance it gives to safety issues identified within the organisation.'*

And:

> *'An effective SMS allows the hazards and risks that could affect your organisation to be identified, assessed and prioritised so that appropriate mitigation measures can be put in place to reduce the risks to as low as reasonably practicable (ALARP).'*

CAP 1059 defines hazard and risk as follows:

> *'A **Hazard** is simply defined as a condition, event or circumstance that has the potential to cause harm to people or damage to aircraft, equipment or structures.*
>
> *A **Risk** is defined as the potential outcome from the hazard and is usually defined in terms of the likelihood of the harm occurring and the severity if it does.'*

CAP 632 states:

> *'During Audits the CAA Inspectors will discuss Safety Management with operators. Their discussions will be based around the SMS evaluation tool...'*

Factual Information

The operator of G-BXFI informed the AAIB that a CAA FSO had informally mentioned SMS during an audit. The operator did not have or subsequently implement a SMS[29]. The AAIB report concerning the accident to G-TIMM[30] on 1 August 2015 revealed that its operator also did not have an SMS in place.

The CAA's General Aviation Unit (GAU) did not have a subject matter expert for SMS. It stated:

> *'There is no formal requirement for the U.K. aviation safety regulator to operate a Safety Management System within applicable national regulations or EU Implementing rules.*
>
> *The CAA has previously used a traditional approach to carrying out safety regulation on the basis of confirming compliance with a regulatory rule set.*
>
> *The CAA is however currently developing a new Regulatory Safety Management System (RSMS).*
>
> *The CAA's RSMS will have a safety governance structure at three levels which develops and uses a risk picture to identify and manage Total Aviation System risks.*
>
> *The General Aviation Unit will integrate with, and operate within the wider RSMS of the CAA using the same processes and tools as the rest of CAA. The RSMS is expected to begin operating in its final form during 2016.'*

Separately, CAA International Whitepaper of 5 April 2016 – *'Implementing a regulatory safety management system to enable performance based regulation, the UK CAA journey so far…'*, stated:

> *'The UK CAA's RSMS sits at the heart of its approach to Performance-Based Regulation (PBR). ICAO Annex 19, combined with the EASA Authority Requirements (ARs) for EU Member States, requires national authorities to implement their own management systems for safety regulation.'*

29 The CAA has stated that it is for the operator to decide whether to implement an SMS.
30 Accident to Folland Gnat G-TIMM, reported in AAIB Bulletin 5/2016.

1.17.3.4 Safety culture

The European Strategic Safety Initiative defines safety culture as follows:

> *'Safety Culture is the set of enduring values and attitudes regarding safety issues, shared by every member of every level of an organisation. Safety Culture refers to the extent to which every individual and every group of the organisation is aware of the risks and unknown hazards induced by its activities; is continuously behaving so as to preserve and enhance safety; is willing and able to adapt itself when facing safety issues; is willing to communicate safety issues; and consistently evaluates safety related behaviour.'*[31]

The Health and Safety Executive (HSE) defines safety culture as follows:

> *'The safety culture of an organisation is the product of individual and group values, attitudes, perceptions, competencies, and patterns of behaviour that determine the commitment to, and the style and proficiency of, an organisation's health and safety management.'*[32]

Eurocontrol[33] provides the following definition:

> *'Safety Culture is the way safety is perceived, valued and prioritised in an organisation. It reflects the real commitment to safety at all levels in the organisation.'*[34]

1.17.4 Approval process for UK civil flying displays in 2015

1.17.4.1 The Air Navigation Order

Article 162 of the 2009 edition of the Air Navigation Order, current at the time of the accident (ANO) (2009) stated:

> *'…no person may act as the organiser of a flying display (in this article referred to as 'the flying display director') without first obtaining the permission of the CAA for that flying display.'*

31 Safety management system and safety culture working group, *'Safety culture framework for the ECAST SMS-WG.'* (European Commercial Aviation Safety Team SMS working group).
32 HSC (1993) ACSNI (Health and Safety Commission Advisory Committee on the Safety of Nuclear Installations) study group on human factors. Third report Organising for Safety. HSE Books.
33 Eurocontrol is the European organisation for the safety of air navigation.
34 Eurocontrol, *'Safety Culture in ATM an Overview.'* (ATM – air traffic management).

Guidance to FDDs and others involved in the organisation of flying displays is provided by the CAA in CAP 403.

Following an application to hold a flying display the CAA may, if it is satisfied that the person is suitable, authorise an individual to be the FDD. CAP 403 states that the FDD is:

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

And:

> *'Before a Permission can be issued, the CAA must be satisfied that: A person is fit and competent as an FDD, having regard in particular to his previous conduct and experience, his organisation, staffing and other arrangements, to safely organise the proposed flying display.'*

The CAA does not define the phrase '*fit and competent'*. It stated:

> *'The CAA must be satisfied of the requirements set out in Article 162 of the ANO. The CAA relies upon the explanatory material contained in CAP 403 Edition 13 (para. 2.2 and 2.3).*
>
> *Currently, an FDD is assessed on the basis of personal knowledge of the CAA's Flight Display Inspector about the individual, his competence and capabilities and any other specific intelligence from prior activities. Also taken into account are the arrangements being made for the flying display. Acceptance of an individual is recorded on the Article 162 permission.*
>
> *This approval is based upon the judgment and knowledge of the CAA's Flight Display Inspector, taking into account the knowledge of the individual in relation to the elements required by the ANO and CAP 403. There is currently (January 2016) no written policy document that describes selection criteria for a person in relation to acceptance as a FDD.'*

The AAIB made Safety Recommendation 2016-032 in Special Bulletin S1/2016 regarding the selection criteria for FDDs (see Section 4.9).

The CAA process for issuing an ANO Article 162 permission, titled: '*Issuing General Aviation Exemptions and Permissions*', required the FSO to review the application form and prepare a site map. Section 8.2 of that document stated:

> *'The principle reason for rejecting an application for a Permission under the ANO 2009 Article 162 is safety. This primarily hinges around the viability of the site for the intended display. Factors such as the proximity of congested areas, heavily used major roads, man-made or natural dangerous obstructions and controlled airspace must be taken into account.'*

1.17.4.2 Ownership of risk

The investigation heard conflicting views about who held the ownership of flying display risk. The FDD and the organisers of the Shoreham Airshow believed that the CAA held the risk and the CAA considered that the risk was held by the organisers and the FDD.

The FDD stated his belief that the CAA issued an Article 162 permission for a flying display only when it was "satisfied that the situation is safe" and that it would intervene if it believed that "everything is not satisfactory".

The organiser expressed the view that the CAA remains "the gatekeeper" of all safety and risk management relating to air displays.

In 2001 the HSE published the document *'Reducing risks, protecting people',* the aim of which was to explain the basis for HSE's decisions regarding the degree and form of regulatory control of risk from occupational hazards[35]. The document notes that the regulatory environment now has to cope with the increasing trend in industry and elsewhere to outsource work and hence risks, and states:

> *'Some of these changes have blurred legal responsibilities for occupational health and safety, traditionally placed on those who create the risks or on those best situated to take steps to control the risks. In certain industries it is often no longer easy to determine who may be in such a position. Though case law has in many instances clarified the situation, the fact remains that for many sectors the above factors make it more difficult to coordinate the adoption of measures for controlling risks. Many more players are involved, some with little access to expertise.*

35 The document does not refer specifically to aviation. It is reported here to provide information about risk ownership in organisational environments more generally.

> *There has in consequence been a growing demand by small firms for a reversion to prescriptive regulation, running counter to the self-regulatory approach – a demand resisted by large firms because they do not face the same problems and are comfortable with the self-regulatory approach. This has resulted in greater emphasis being placed on the need for clarity of the status and content of the guidance element of the architecture of regulation.'*

1.17.4.3 Risk assessment of flying displays

CAP 403 states:

> *'Displays must be carefully planned both on the ground and in the air and nothing should be considered without careful thought to ensure that it is safe. A risk assessment procedure is included to help in this process.'*

This process was included in Appendix A to CAP 403, which among other things provided tables for deciding levels of severity and likelihood of an occurrence. CAP 403 set out a five-step process, as follows:

> *'1. Identify the hazards associated with activities contributing to the event, where the activities are carried out and how they will be undertaken*
>
> *2. Identify those at risk and how they may be harmed*
>
> *3. Identify existing precautions*
>
> *4. Evaluate the risks*
>
> *5. Decide what further actions may be required, i.e. mitigation.'*

This process is similar to those suggested by the HSE, the Event Industry Forum and others. The HSE states that risk assessments should be conducted by a competent person and defines such a person as:

> *'…someone who has sufficient training and experience or knowledge and other qualities that allow them to assist you properly. The level of competence required will depend on the complexity of the situation.'*

1.17.4.4 Hierarchy of control

The HSE and other safety organisations use a 'hierarchy of control' for mitigating hazards, listing control measures in order of decreasing effectiveness, as follows:

1. Elimination (e.g. remove the hazardous element entirely)
2. Substitution (e.g. replace the material or process with a less hazardous one)
3. Engineering Controls (e.g. separate the hazard from others by enclosing or guarding)
4. Administrative Controls (e.g. use warning signs, briefings and procedures)
5. Personal protective clothes and equipment (if controls 1-4 have all been found ineffective)

1.17.4.5 Hazardous materials risk assessments

CAP 403 states that:

> *'…risk assessments should contain specific mitigation for dealing with any aviation materials which could become unstable following an accident.'*

And:

> *'Event Organisers should be aware of the increasing use of hazardous materials, such as carbon fibre, in modern military and civil aircraft construction. Information on such hazards should be included in the risk assessment.'*

1.17.5 Organisation of the Shoreham Airshow

The Shoreham Airshow was organised by a company formed specifically to run it, which leased the aerodrome from the aerodrome operator for the period surrounding the event. The organiser contracted a specialist safety consultancy to produce an Event Plan, an Emergency Response Plan, risk assessments for the ground operations (referred to later as the ground operations risk assessment), and to liaise with the emergency services. An Emergency Services Group (ESG) comprising members of the local emergency services, the local authority and others provided comment on the Event Plan and Emergency Response Plan. Elements of the event required a licence from the local authority, but this did not include the flying display itself.

The FDD booked the display acts, arranged the Article 162 permission from the CAA, was responsible for the flying activity, and attended the ESG meetings and a 'table-top' simulated emergency response exercise.

The FDD provided participants with a briefing document which contained event timings, rules for the flying display, restrictions, and a copy of the Article 162 permission including the CAA-issued map of the flying display area. Section 4 of the briefing document stated:

> *'Display pilots are aware of the fact that their aircraft must be operated in accordance with any airworthiness limitations and that only manoeuvres that are known and have been practiced are to be flown…Furthermore, aircraft positioning at all times to be such that, in the event of an engine or airframe failure causing a forced landing or ground impact, this would be outside the crowd area.'*

The second paragraph of Section 18 of the briefing document, '*Emergency, Fire, Medical and Security*', stated:

> *With the increasing number of earlier jets participating in displays, would pilots concerned please brief the fire crew or Display Park Director of any special requirements or procedures regarding fire handling and the safety of ejector seats.'*

The Shoreham FDD had completed a risk assessment relating to the flying display, which stated, in part:

> *'For the effective safety management of Flying Display Operations at Shoreham RAFA Air Display 2015 it is essential that all Airshow-specific aircraft operations, both on the ground and in the air are assessed and the risk quantified.'*

The risk assessment document listed ten hazards that had been identified and subject to risk assessment:

> *'Airside unauthorised access*
>
> *Mid-air collision – Display and non-Display aircraft*
>
> *Mid-air collision - Display formation*
>
> *Ejector seat impacts crowd*
>
> *Loss of control due to pilot disorientation*
>
> *Location Road and of local built up areas*
>
> *Public Assembly on A27 and local roads*

Aircraft Crash Outside the Airfield Boundary

Fast Jet aircraft collision into crowd area

Fatigue amongst key safety staff'

Each hazard was considered based on a probability of occurrence (Figure 18) and the severity of the consequence (Figure 19). An acceptability matrix (Figure 20) was then applied which defined the risk associated with each hazard as either:

"acceptable' (may be continued without further reference)

'unacceptable' (positive actions must be taken to reduce the risk to an acceptable level before the activity is undertaken)

'review' (review must be undertaken at the earliest opportunity in an effort to reduce the risk to an acceptable level)'

CLASSIFICATION	FREQUENT	OCCASIONAL	REMOTE	IMPROBABLE	EXTREMELY IMPROBABLE
Quanlitative Definition.	Likely to occur many times during the Shoreham RAFA Air Display 2015.	Likely to ocur sometime during the Shoreham RAF Air Display 2015.	Unlikely but possible to occur during the Shoreham RAFA Air Display 2015.	Very Unlikely to occur during the Shoreham RAFA Air Display 2015.	Almost inconceivable event will occur during the Shoreham RAFA Air Display 2015.
Quantitative Definition.	Definition not required as the Flying Display programme is regulated to one aircraft or one formation displaying at any time.				

Figure 18

Probability of occurrence table

CLASSIFICATION	CATASTROPHIC	HAZARDOUS	MAJOR	MINOR	NEGLIGIBLE
Results in one or more of the following effects	◊ Total loss of one or more aircraft and/ or multiple fatalities as a result of an aircraft incident during the Shoreham RAFA Air Display 2015 that may or may not lead to Display Cancellation.	◊ Major aircraft damage and/ or a single fatality as a result of an aircraft incident that may or/ may not lead to a prolonged or permanent suspension of the Flying Display.	◊ Serious aircraft incident leading to the temporary suspension of the Flying Display.	◊ Minor aircraft incident that could result in interruption to the Flying Display.	◊ No effect on Shoreham RAFA Air Display 2015.

Figure 19

Consequence severity table

PROBABILITY / OUTCOME	EXTREMELY IMPROBABLE	IMPROBABLE	REMOTE	OCCASIONAL	FREQUENT
CATASTROPHIC	REVIEW	UNACCEPTABLE	UNACCEPTABLE	UNACCEPTABLE	UNACCEPTABLE
HAZARDOUS	REVIEW	REVIEW	UNACCEPTABLE	UNACCEPTABLE	UNACCEPTABLE
MAJOR	ACCEPTABLE	REVIEW	REVIEW	REVIEW	UNACCEPTABLE
MINOR	ACCEPTABLE	ACCEPTABLE	ACCEPTABLE	ACCEPTABLE	REVIEW
NEGLIGIBLE	ACCEPTABLE	ACCEPTABLE	ACCEPTABLE	ACCEPTABLE	ACCEPTABLE

Figure 20

Acceptability matrix

HAZARD NUMBER	HAZARD DESCRIPTION	S	P	R	MITIGATION	ACTIONS REQUIRED	BY WHOM
8	Aircraft Crash Outside the Airfield Boundary	C	I	U	Display regulations require pilots to observe the normal Rules of the Air when outside the display area.	All crews to be briefed on safety requirements and mandatory operating regulations prior to each display flight.	FDD
					There are the major restrictions on displaying aircraft that require them to be at specific minimum heights when over specific areas around the display site.	All flights to be monitored by the FDD and FCC to ensure compliance with the regulations, observance of agreed display programme and consistency of presentation.	FDD & FCC
					Pilots will be specifically briefed on this restriction at the display briefing.	FDD and CFCC to have direct radio contact with the display pilot and can intervene to stop the display at any time.	FDD & CFCC

Figure 21

Example hazard: 8 - Aircraft Crash outside the airfield boundary

At the time of the accident, CAP 403 did not require risk assessments to be submitted to the CAA when applying for approval to hold a flying display. The CAA informed the AAIB that when considering applications for flying displays, and when attending flying displays to conduct inspections, it did not inspect or request copies of hazard logs or risk assessments.

The FDD of the Shoreham display was the FDD at two flying displays after 22 August 2015, for which he applied to the CAA for Article 162 permissions. The risk assessments he presented to the CAA in support of these applications were not materially different from that for Shoreham. Article 162 permissions were issued in both cases and the FDD stated that he interpreted this as confirmation these risk assessments were considered fit for purpose.

1.17.6 Independent review of risk assessment

The AAIB commissioned a review by the Health and Safety Laboratory (HSL) of the risk assessment for the 2015 Shoreham Airshow. The complete HSL report is included at Appendix J.

The HSL considered the risk assessment in the context of guidance available in CAP 403 and elsewhere, and included a comparison with the corresponding risk assessments for two other flying displays at Shoreham. It did not compare the risk assessment with risk assessments from flying displays other than those, and did not determine whether it was "better" or "worse" than the norm. The HSL was not asked to report on any other activities undertaken by the FDD. Its report concluded that the risk assessment did not fully comply with the guidance given in CAP 403. It stated:

> *'It was found that the Shoreham Airshow Air Display Risk Assessment contained a number of deficiencies compared to what would be expected for a risk assessment to control risks to the public. There is little, or no, evidence that:*
>
> - *all relevant parties were consulted in the assessment of the hazards and risks,*
> - *a comprehensive list of foreseeable hazards was identified,*
> - *sufficient and achievable mitigation measures were considered and implemented,*
> - *lessons were learned from near misses or incidents at previous airshows (either previous Shoreham airshows or other airshows)*
>
> *There is no demonstration that the hazards and risks identified have been managed sufficiently.*
>
> *The risk assessment does not fully comply with the CAA guidance for air displays…*
>
> *The conclusion of the review is that the 2015 Shoreham Airshow Air Display Risk Assessment is not fit for the purpose of identifying and mitigating the risks and hazards to the public from the air display activities of the airshow.'*

Factual Information

The following Safety Recommendation was made in the AAIB Special Bulletin S1/2016:

Safety Recommendation 2016-031

It is recommended that the Civil Aviation Authority review and publish guidance that is suitable and sufficient to enable the organisers of flying displays to manage the associated risks, including the conduct of risk assessments.

The CAA responded in Follow-up Action on Occurrence Report (FACTOR) F4/2016, published on 9 June 2016, as follows:

'The CAA has accepted the recommendation that it should review its guidance. It remains the responsibility of the organisers of flying displays to follow this guidance and conduct risk assessments that are suitable and sufficient to manage the risks associated with the air displays that they are organising.

The CAA reviewed its guidance and published updated guidance on 3 May 2016 in an updated version of the CAA's document 'Flying displays and special events: A guide to safety and administrative arrangements.'

The AAIB commissioned a further HSL study to consider the risk assessment guidance provided by CAP 403 Edition 13. This report is included at Appendix K.

The HSL report concluded:

'A number of observations have been made of good practice in hazard and risk assessment in CAP 403. There are some areas of the guidance, however, where additional information could be of benefit to those using it and would potentially lead to greater confidence that a risk assessment created using the guidance will be suitable and sufficient for managing the risks.

This study has identified areas of the guidance where changes are required to give airshow flying display organisers the information needed to undertake meaningful risk assessments, or in some cases, to avoid misleading organisers on what needs to be done. Ultimately, these improvements should ensure that the risk assessments help airshow organisers to target and control the risks from flying displays.'

It recommended that:

- CAP 403 should clearly list the qualifications and experience required of the people who should be involved in assessing the risks.
- CAP 403 should include additional information to stress the importance of the hazard identification process to the quality of the overall risk assessment.
- CAP 403 guidance could also recommend that a record be kept of the hazard identification process.
- CAP 403 is potentially misleading in the area of risk mitigation. This is a significant area that needs to be improved as failing to properly assess the mitigation measures could lead to inappropriate or unachievable measures being put in place that do not control or reduce the risks.
- It should be explicitly stated that an explanation should be recorded of how the identified mitigation measures lower the classification of severity or likelihood.
- The tolerability of risk criteria should be reviewed as some high consequence events are deemed "tolerable" for relatively frequent likelihoods.

The report identified other modifications that might assist flying display organisers and risk assessors.

The CAA updated its response to Safety Recommendation 2016-031 in FACTOR F4/2016 Issue 2, published on 24 January 2017, as follows:

> *'The CAA will review the findings contained in the HSL reports on the management of risk, in conjunction with the conclusions of its post-implementation review of UK Civil Air Displays.*
>
> *The CAA will complete this review and publish any updated guidance by April 2017.'*

1.17.7 Sequential listing of manoeuvres

At the time of the accident there was no requirement for the organisers of flying displays or FDDs to be provided with the sequential listing of manoeuvres to be flown by each act.

The AAIB explored the regulation of flying displays in other countries where there is some regulation of flying display activity. The circumstances in these countries may be different from those in the UK, but provide examples of other frameworks[36]. For example, in relation to the sequential listing of manoeuvres, Transport Canada (the aviation regulator in Canada) requires organisers of flying displays to provide the following information at least 10 days before the intended flying display:

> *'…sequential listing of all manoeuvres to be flown by the performer, including:*
>
> *(i) the distance of each manoeuvre from spectator areas, including, where applicable, the point of entry into and recovery from each manoeuvre,*
>
> *(ii) the point of entry to, and departure from, the flying display area, where applicable,*
>
> *(iii) the directions of flight relative to the spectator areas,*
>
> *(iv) the location of water drops, pyrotechnics, helicopter rappelling and similar operations relative to the spectator areas,*
>
> *(v) the maximum and minimum speeds for the entire performance, and*
>
> *(vi) the minimum altitudes for each manoeuvre to be performed'*

1.17.8 Airworthiness and national permits to fly

ICAO International Standards and Recommended Practices, Annex 8, Airworthiness of Aircraft, defines the following terms:

> *'**Airworthy**. The status of an aircraft, engine, propeller or part when it conforms to its approved design and is in a condition for safe operation.*

36 The CAA noted that a number of other EU Member States follow the "UK model" and CAP 403

***Continuing airworthiness**. The set of processes by which an aircraft, engine, propeller or part complies with the applicable airworthiness requirements and remains in a condition for safe operation throughout its operating life.*

***Maintenance**. The performance of tasks required to ensure the continuing airworthiness of an aircraft, including any one or combination of overhaul, inspection, replacement, defect rectification, and the embodiment of a modification or repair.'*

The 2009 edition of the ANO, current at the time of the accident, set out the regulations concerning national permits to fly, including:

'21 Issue of national permits to fly

(1) Subject to paragraph (2), the CAA must issue for any non-EASA aircraft registered in the United Kingdom a national permit to fly if it is satisfied that the aircraft is fit to fly having regard to the airworthiness of the aircraft and the conditions to be attached to the permit….

...The CAA may issue a national permit to fly subject to such conditions relating to the airworthiness, operation or maintenance of the aircraft as it thinks fit.

Nothing in this Order obliges the CAA to accept an application for the issue, variation or renewal of a national permit to fly if the application is not supported by such reports from such persons approved under article 244 as the CAA may specify, either generally or in a particular case or class of cases.

22 National permits to fly ceasing to be in force and issue of airworthiness directives for permit aircraft

(1) A national permit to fly ceases to be in force if:

(a) the CAA has issued a directive that requires:

(i) an inspection to be carried out for the purpose of ascertaining whether the aircraft remains airworthy; or

(ii) modification or maintenance of the aircraft or any of its equipment necessary for the airworthiness of the aircraft for the purpose of ensuring that the aircraft remains airworthy; or

(b) completion of an inspection, modification or maintenance of the aircraft is required as a condition of the permit to fly.

A national permit to fly which has ceased to be in force under paragraph (1) comes into force again as soon as:

(c) any such inspection, modification or maintenance has been satisfactorily completed; and

(d) in the case of an inspection, any consequential repair, replacement or modification has been satisfactorily carried out.

A national permit to fly ceases to be in force:

(e) if any condition (other than a condition of the permit requiring an inspection, modification or maintenance) is not complied with;

(f) if the aircraft, engines or propellers, or such of its equipment as is necessary for the airworthiness of the aircraft, are modified or repaired, unless the repair or modification has been approved by the CAA or by a person approved by the CAA for that purpose.

A national permit to fly is not in force unless the permit includes a current certificate of validity issued by the CAA or by a person approved by the CAA for that purpose.

In this article a certificate of validity means a certificate which certifies that a national permit to fly remains valid for the period specified in the certificate and a certificate of validity is current during that period.'

1.17.9 Acceptance and maintenance of ex-military aircraft on the UK civil register

An aircraft is "airworthy" if it complies with all relevant regulations and requirements of a national certifying authority such as the CAA. The design standard for acceptance of an ex-military aircraft such as G-BXFI is defined in an Airworthiness Approval Note (AAN), and its initial airworthiness is certified by the CAA issuing a National Permit to Fly (NPF). These will include any conditions and limitations under which the aircraft may be flown and any relevant airworthiness, operation or maintenance requirements that are to be met.

Appendix L shows the AAN for G-BXFI, No. 26172 Issue 2, dated July 2008. Appendix C shows the NPF for G-BXFI.

The CAA issues an AAN after reviewing an aircraft and its documentation, based on a technical report submitted by the applicant organisation. The AAN is unique to each aircraft and forms the basis of its airworthiness approval. The AAN defines the technical standard of an aircraft and its operational limitations, the documents required to maintain and operate it and any additional requirements applicable at the time of issue. It is a 'snapshot' of the aircraft's status at the time it was placed on the civil register but may be revised by the CAA to reflect changes in an aircraft's modification standard or a change of a limitation or requirement. The AAN does not usually specify the amendment status of each document listed.

An internal CAA Airworthiness Division Technical Procedure, TP-DAW-23-2 *'Ex Military Aircraft on a Permit to Fly'* dated 4 July 2012, describes the airworthiness design procedures and standards applied to ex-military aircraft operating on a NPF and provides guidance to CAA Surveyors when considering ex-military aircraft for acceptance onto the UK civil register. This document describes the application process for a NPF, the technical information that should be provided with the application and the information that should be considered for inclusion in the aircraft's AAN.

For fixed wing aircraft with a mass greater than 2,730 kg the initial application for a NPF must be submitted by an organisation approved for that purpose under BCAR A8-20 – Group E4 Design Assessment or, since November 2013, BCAR A8-25 Supplement 2.

When issued, the NPF is considered to be 'non-expiring'. In order to validate the NPF, and to verify that the aircraft remains compliant, an annual submission must be made to the CAA confirming that the aircraft continues to satisfy the requirements of its NPF. This submission includes confirmation that the aircraft is compliant with the requirements of the AAN and all applicable MPDs. When this submission has been verified, a Certificate of Validity (C of V) is issued for the aircraft.

At the time of the accident, the CAA required that ex-military jet aircraft on the UK civil register were maintained by organisations holding approvals under BCAR A8-20, 23 or 25[37]. The privileges granted to a BCAR A8-20 approved organisation (such as the organisation responsible for the maintenance of G-BXFI) allow it to 'self-certify' that an aircraft continues to meet the requirements of its NPF and to issue a C of V. The CAA has no requirement to check that such self-certifications are valid but it does perform general compliance audits as part of its oversight of approved organisations.

37 At the time of publication the CAA requires that ex-military jet aircraft on the UK civil register are maintained by organisations holding approvals under BCAR A8-23 or -24 and managed by organisations holding approvals under BCAR A8-25. The period for organisations to transition from A8-20 to A8-23 or -24 and -25 ended in January 2016.

The continued airworthiness of the aircraft is then subject to its operation within specified limitations, a programme of approved maintenance and defect rectification, and compliance with any additional MPDs.

The relevant airworthiness procedures were contained in CAP 733 – *'Permit to Fly Aircraft'* and Chapter A3-7 of CAP 553 – '*BCAR* [British Civil Airworthiness Requirements] *Section A – Airworthiness Procedures where the CAA has Primary Responsibility for Type Approval of the Product*'.

1.17.10 Maintenance organisation approval

The organisation responsible for the aircraft's maintenance at the time of the accident was contracted by the aircraft operator to provide all maintenance and continuing airworthiness functions for G-BXFI. It held BCAR A8-20 *'M5 maintenance'* and *'E4 design'* approvals. These approvals allowed the organisation to restore and maintain former military aircraft for operation on the UK civil register. The requirements of the approvals are defined in Chapter A8-20 of CAP 553. An Exposition approved by the CAA contained the management organisation, maintenance procedures and quality procedures, also known as Quality Management System (QMS), for the organisation.

1.18 Additional information

1.18.1 The accident manoeuvre

The pilot referred to the planned manoeuvre as a 'bent loop', a variation of a conventional loop involving a rolling element.

A loop is entered from straight and level flight. The nose of the aircraft is then pitched up continuously, passing through the inverted attitude at the apex and continuing through the downward vertical until the aircraft returns to the required height in a straight and level attitude. The entry and exit ground track is the same. See Figure 22.

The pilot described the bent loop as a manoeuvre performed by entering a loop and, towards the end of the first quarter, just before the aircraft is vertical, rolling the aircraft a desired amount while continuing to pitch the nose up. The aircraft continues pitching nose-up, pulling through the second half of the loop, which results in the exit track being different from the entry track by the amount of roll applied. See Figure 23. He added that his normal technique was to change the aircraft heading and resulting track by part of the desired amount on the upward vertical, and adjusting the heading on the downward vertical to achieve the desired exit track.

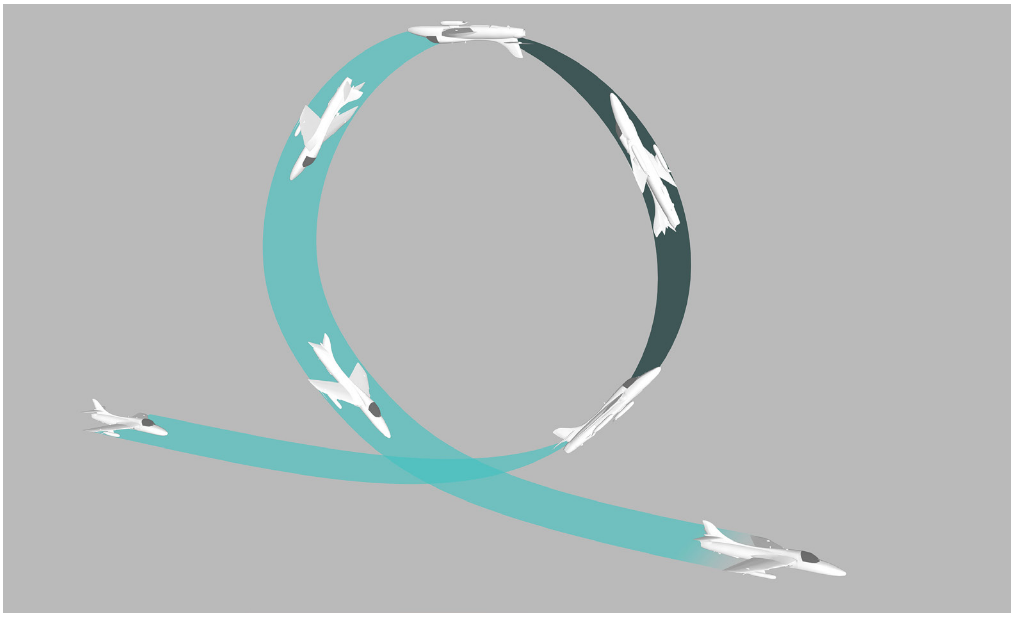

Figure 22

Loop

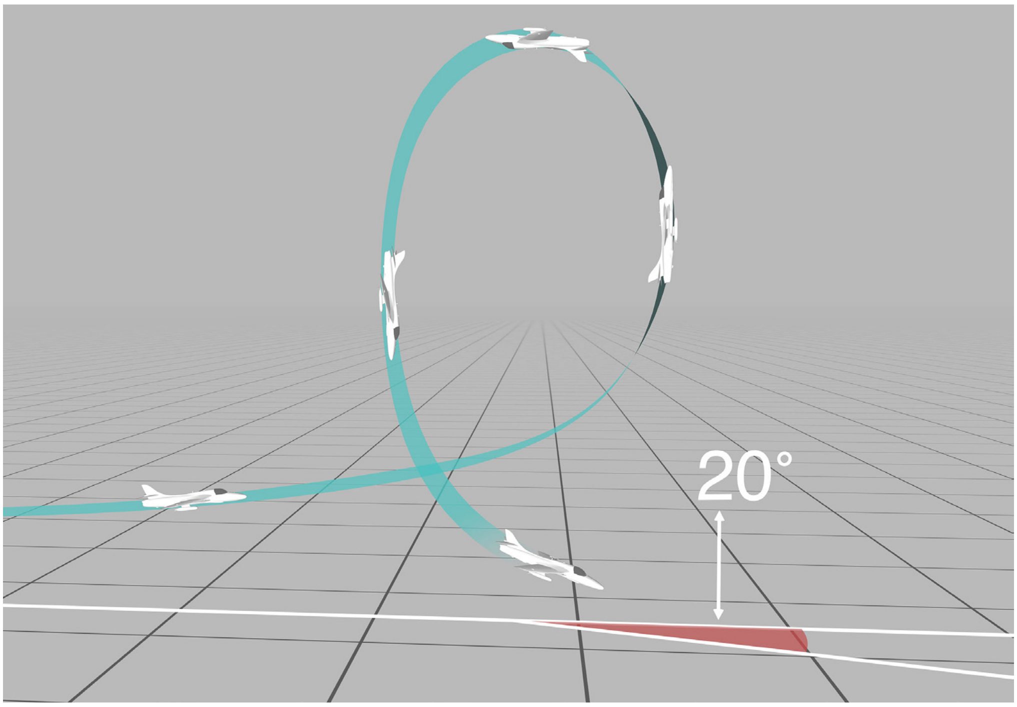

Figure 23

Manoeuvre with vertical component and roll resulting in a change of ground track

In the accident manoeuvre the aircraft rolled through a greater angle than in the manoeuvre intended by the pilot and resulted in an exit ground track approximately 60° right of the entry ground track.

The pilot stated that he had not noticed any problems with the altimeters but commented that he only used the altimeter in front of him (the left altimeter) and not the altimeter on the right. The pilot's description of altimeter operation in G-BXFI indicated that he was not familiar with selection of the altimeter between standby and servo mode, and that he was not in the habit of changing between these modes.

Members of the FCC estimated the height of the aircraft at the apex of the accident manoeuvre. The lowest height estimated was 1,800 ft and the highest estimate was 2,500 ft.

1.18.2 Aircraft handling

The TP was asked to describe the method for flying a loop and a loop with a rolling component, in a Hawker Hunter, using the minimum entry speed of 350 KIAS declared by the accident pilot. The TP also described an escape manoeuvre that could be flown if thrust was lost during the first half of the manoeuvre or if a safe gate height was not achieved. His descriptions are set out below.

1.18.2.1 Flying a loop

'At 350 KIAS and in straight and level flight, select full power and make an aft stick input to pull up initially at approximately 4g, and maintain this until in the vertical. If buffet onset occurs during this phase the pull force should be adjusted to maintain buffet onset. Once through the up-vertical the pull force should be adjusted to achieve a pitch rate that ensures that the height at the apex is above the gate height. At the apex, which is cued to the pilot by the nose being slightly above the horizon, the height and speed are checked. If above the gate height and below the maximum speed, the loop is continued by modulating the pull force on the stick to give a positive pitch rate to ensure that the aircraft is in level flight at no lower than the permitted minimum height.

It should be noted that the pitch rate in the third quarter of the loop (apex to down-vertical) should be high enough that the pull force and g are reducing in the latter stages of the manoeuvre as level off is approached. The power may be reduced at or past the apex of the loop to achieve an airspeed at level off which is the entry speed

> *for the next manoeuvre, typically a reduction to about half throttle at the apex. If at the apex the aircraft is below the gate height or the speed is above the maximum (defined because the higher the speed at the apex, the higher the g needed to achieve the radius required during the pull through), an 'escape manoeuvre' is flown by moving the stick forward to achieve close to zero pitch rate, then smoothly rolling to wings level and then gently pulling back on the stick to achieve level flight. The nose will drop during this manoeuvre and speed will increase, and if the airspeed is very low at the apex then, prior to rolling, the pitch rate can be maintained to place the aircraft into a shallow dive with increasing airspeed before commencing the roll.'*

If flaps are used during a loop, they should be selected once the speed has reduced below 300 KIAS during the pull up; this requires an increase in the pull force on the stick to counter the nose-down trim change due to the flaps and, if required, to use the increase in g that the flaps will provide. During the downwards half of the loop, the flaps should be selected up at a speed to ensure that they are up before accelerating through 300 KIAS.'

1.18.2.2 Flying a 'bent loop'

> *'If the exit heading from a loop is required to be different to the entry heading, there are several means of achieving this, and one is to 'bend' the loop by gently rolling during the upwards first half. If the exit heading is required to be greater than the entry heading (i.e. to the right) the aircraft is rolled left and vice versa.*
>
> *The technique for this is to enter as per a 'straight' loop but approaching the up-vertical to pick a point on the horizon to roll towards such that the nose tracks through that point, wings level, at the apex and then gives the required exit heading. For example, for a 90 degree bend, that point is directly abeam the pilot as he looks out of the side of the canopy towards which he will roll. Having chosen that point, the pilot commences a gentle roll towards the chosen point on the horizon whilst simultaneously reducing the pull on the stick slightly in order to achieve the same apex height as for a 'straight' loop. The roll rate is modulated to achieve wings level with the nose directly above the chosen point, and then the loop is completed as for a "straight" loop.'*

1.18.2.3 Technique for a loss of thrust during the upward half of a loop

> *'Any loss of thrust during the first half of a loop that has been planned to be flown with a high power setting will require the aircraft to be flown to achieve wings level flight at a suitable airspeed (gliding speed if a total power loss has occurred) as soon as possible. If the power loss occurs at or after passing the up vertical, the loop is continued and an escape manoeuvre flown at or just past the apex as described above. If it occurs before the up vertical the aircraft should be rolled inverted and the nose pulled towards the horizon. On reaching the apex attitude (nose just above or on the horizon), an escape manoeuvre as described above should be flown. Even following a total engine failure, the elevator and aileron accumulators should allow the control inputs required for these manoeuvres to be made before the flying controls revert to "Manual" and, therefore, the aircraft response to control inputs would be normal. Once the escape manoeuvre has been completed an attempt can, if appropriate, be made to regain power. If power cannot be regained, the aircraft can be positioned for a forced landing if sufficient energy and a suitable runway are available. If not, it can be pointed into as safe an area as possible prior to ejection.'*

1.18.2.4 Entry speed

> *'In aircraft such as the Hunter, the pilot should have derived and nominated a minimum entry speed for each looping manoeuvre that he will fly. Invariably, this speed will be higher if the manoeuvre involves pulling down through the vertical in the second half, such as a complete loop, than if it is an upwards half loop or a manoeuvre such as a half Cuban 8 (5/8 loop with a 180° roll from inverted to erect on a down 45° line followed by a pull back to level flight). The minimum speed used will be predicated on having a specified power setting and a minimum entry height. If the minimum speed is not achieved then the manoeuvre is not entered and there may be several options for a replacement manoeuvre. For example, if the minimum speed for a complete loop is not achieved but that for a half Cuban 8 is then the latter manoeuvre may be flown. However, the option to just fly through into the following manoeuvre always exists. Looping manoeuvres will invariably be entered above the minimum speed but if too much above then the resulting apex height increase may be excessive, the G pulled may also be excessive, and the exit speed may be wrong for the following manoeuvre. Therefore, energy needs to be managed well in order to achieve the required entry speed for a looping manoeuvre.'*

1.18.2.5 Minimum apex ('gate') height

> *'In order to complete safely the downwards half of a looping manoeuvre a pilot will have a nominated minimum or "gate" height which the aircraft must be above. There will usually be a maximum airspeed associated with the gate height because, if above this speed, excessive g will be required in order to achieve the same radius, possibly resulting in an aircraft overstress or physiological problems for the pilot. Also, if the Mach number increases significantly then elevator/tailplane effectiveness may be reduced such that it may not be possible to achieve the required g.*
>
> *If the aircraft is below the gate height at the apex of a loop then the pilot flies an escape manoeuvre which consists of a smooth roll through 180° back to erect flight. The nose will drop into a shallow dive during this roll but this results in an increase in airspeed which helps with the pull back to level flight. If the airspeed is very low at the apex the pilot may continue to pull the aircraft into a shallow [inverted] dive to increase airspeed before commencing the roll. Despite an escape manoeuvre resulting in a shallow dive, if the aircraft has completed an upwards half loop then sufficient height should always be available to complete* [the escape manoeuvre] *back to level flight safely.'*

1.18.2.6 Entry criteria for low-speed aircraft such as the RV-8

> *'Low-speed aerobatic aircraft have a small looping radius and a high pitch rate. Therefore, there is little variation in the height gained from pull up and insufficient time at the apex to check height, compare it to a 'gate' height, decide whether to continue or to abort and then complete an escape manoeuvre without exiting in a very steep dive which could, if roll performance is poor, result in a greater height loss than continuing the loop. Therefore, in low speed aircraft an apex gate height will usually not be used but a minimum entry height will be used in addition to a minimum entry speed. If the loop entry speed is above maximum level flight speed then the manoeuvre will be entered from a dive and, in order to have the required exit speed to fly the following manoeuvre, the exit height will normally be below the pull-up height. So saying, in most aircraft you could pull out to exit at the pull-up height but the completion speed would be significantly less than the pull-up speed.'*

1.18.2.7 Correct use of gate heights

The AAIB was not able to obtain a comprehensive insight into the use of gate heights by display pilots. However, two pilots other than the accident pilot, who had relevant military and fast jet experience and were interviewed in the course of the investigation, volunteered that they had used an incorrect gate height during a display, or omitted to check a gate height.

1.18.3 Review of recorded imagery by the Test Pilot

1.18.3.1 Background

The TP made observations on the following image recordings:

- Cockpit and external image recordings of the display flown at Duxford on 13 September 2014.
- Cockpit and external image recordings of the display flown at Shoreham on 30 August 2014.
- The accident manoeuvre at Shoreham on 22 August 2015.

His comments are set out below.

1.18.3.2 Flying display at Duxford in 2014

Loop:

'The external video shows that the loop was flown with some flap selected through all portions when the flaps were visible. The airbrake was selected out during the turn after the arrival pass and remained out throughout the first half of the loop up to the apex although when the aspect allowed the airbrake to be seen again (just before the down vertical line) it had been retracted. The in-cockpit video shows that in the decelerating turn following the arrival pass a flap selection was made at 360 KIAS although it was not possible to identify any airbrake selections. 12 seconds before pull-up full power was selected and 8,000 rpm indicated (8,100 rpm audio) and this was maintained until the apex when a power reduction was made; the minimum rpm during the second half of the loop was 7,200 rpm indicated (7,000 audio) but it was varying and flown mainly with an average of 7,500 rpm indicated.

Eight seconds before pull-up the airspeed was 320 KIAS and increasing. Pull-up to apex was 15 seconds, and 2 seconds past the apex the airspeed was increasing through 150 KIAS and the *height (from the right instrument panel altimeter) was 4250 ft aal. The manoeuvre was completed 30 seconds after pull-up at 320 KIAS and with a minimum altimeter reading of 400 ft. Overall, this manoeuvre was, with the exception of the airbrake being out for the first half, in accordance with the pilot's declared nominal parameters. There was no logical reason to have flown the start of the loop with the airbrake out whilst having full power selected. Therefore, it is probable that either the pilot forgot to select it in before pull-up or an 'in' selection had been made but was not effective and was not noticed by the pilot. However, it appears that a successful 'in' selection was made close to the apex.'*

First half Cuban 8:

'The external video shows that some flap was selected throughout the manoeuvre. The pull-up was from 360 KIAS and 250 ft indicated on the altimeter with full power, although a small aft throttle input was made just after pull-up, followed by an almost immediate reselection of full power. These small throttle movements, that result in a power changes of about 800 rpm indicated, are seen on the majority of occasions in the looping manoeuvres although they would have had no effect on the manoeuvres at all. Approximately three seconds past the apex the airspeed was increasing through 200 kts with the altimeter indicating a height of 4,500 ft. The manoeuvre was completed at 400 KIAS and 300 ft when the aircraft entered a right turn. The final pull out was controlled and the aerobatic minimum of 500 ft could easily have been captured.'

Second half Cuban 8:

'The external video shows that this was flown with the flaps up. The pull-up was from 430 KIAS at 300 ft with 7,950 rpm indicated (8,050 audio) although the power was reduced to 7,400 rpm indicated (7,130 audio) just after pull-up. Five seconds past the apex the altimeter was reducing through 4,700 ft with the airspeed increasing through 230 KIAS at which point the roll was commenced. The manoeuvre was completed with 7,950 rpm indicated (8,050 audio) set, and at 410 KIAS and 300 ft in a similar manner to the first half Cuban 8.'

1.18.3.3 Flying display at Shoreham in 2014

'Bent loop':

> *'This was flown with some flap selected during the turn before pull-up and maintained until after completion of the manoeuvre. The pull-up was initiated whilst rolling out of the left hand turn and was made with 6,720 rpm indicated (6,720 audio) set. The power was subsequently increased to 7,850 rpm indicated (7,920 audio) by the apex, then during the downward half reduced to 7,500 rpm indicated (7,180 audio) and increased finally to 7,930 rpm indicated in the subsequent climb but when passing through level flight was 7,610 rpm indicated (7,800 audio). The time from pull-up to apex was approximately 2 seconds less than for the 2015 display indicating that the 2014 manoeuvre was flown with a higher mean pitch rate. The test data indicates that the upward part of the 2015 accident manoeuvre had to have been flown at maximum instantaneous turn performance in order to have achieved such a low apex height. Therefore, to have achieved a higher pitch rate in 2014 the airspeed must have been greater, indicating that the airspeed at pull-up was greater in 2014 than in 2015. A slight pitch-rate reduction occurred passing the down-vertical line and the level-off on completion of the loop was smooth, indicating that the apex height had a comfortable margin above what was required for a safe gate height. The exit heading was along the display line parallel to the crowd.'*

Half Cuban 8s:

> *'Two half Cuban 8s were flown, both with some flap selected throughout. The rpm at pull-up for the first one was 7,650 rpm indicated, reached 8,000 rpm indicated (8,050 audio) and at the apex this was increased to 8,050 rpm indicated (8,100 audio). For the second, the pull-up was flown with 8,030 rpm indicated (8,060 audio) selected and the rpm was then reduced to 7,370 rpm indicated (7,180 audio) in the climb and increased to 7,500 rpm indicated (7,430 audio) at the apex. The JPT with full throttle selected appeared to be slightly higher than on take-off and was possibly up to 580°C.'*

1.18.3.4 Flying display at Shoreham in 2015

Accident manoeuvre:

'The accident manoeuvre had several significant deviations from the nominal parameters that the pilot stated he used for a Bent Loop. Specifically:

The entry airspeed of 310 KIAS +/- 15 kt was 25 - 55 KIAS less than the declared nominal value of 350 KIAS.

- *The rpm at pull up (derived from the spectrum analysis of the action camera audio) was 7,530 audio, which reduced to less than 6,800 audio, possibly as low as 6,500 audio during the upward half of the manoeuvre and was increased transiently to 7,210 audio. It was 7,010 audio at the apex. This was contrary to the pilot's declared nominal power setting of increasing to full power at or shortly after the pull-up. The throttle was not visible on the video and so it is not possible to confirm whether the rpms were pilot selected or due to an engine malfunction.*
- *The airspeed at the apex of the manoeuvre was 105 +/-2 KIAS which was at the very bottom of his stated acceptable airspeed range.*
- *The manoeuvre was continued into the downward half of a loop although the apex height of approximately 2,700 ft was significantly below the lowest value of 3,500 ft that the pilot stated was required to complete the manoeuvre in order not to descend below his 500 ft aerobatic minima.*
- *The downward half of the manoeuvre had a flightpath that tracked straight along the A27 and there appeared to be no attempt to change the flightpath in order to track away from that road.*

The accident manoeuvre featured very low energy. Of the other six looping manoeuvres analysed, no others had such a significantly low entry speed when compared to that of the nominal manoeuvre described by the pilot, and the low power during pull-up of the accident manoeuvre was not seen in any other. Therefore, all of the other manoeuvres had an apex height above the minimum gate height. The combination of low entry speed and less than maximum thrust meant that the apex height was below the minimum gate height of 3,500 feet and the airspeed at the apex was 105 +/- 2 KIAS. This was the lowest apex airspeed identified

> *by the pilot of G-BXFI and was less than his normally expected airspeed of 150 KIAS. In these circumstances the correct action would have been to perform an escape manoeuvre; rolling erect and then pulling out of the resulting dive* [shown in Figure 24].*'*

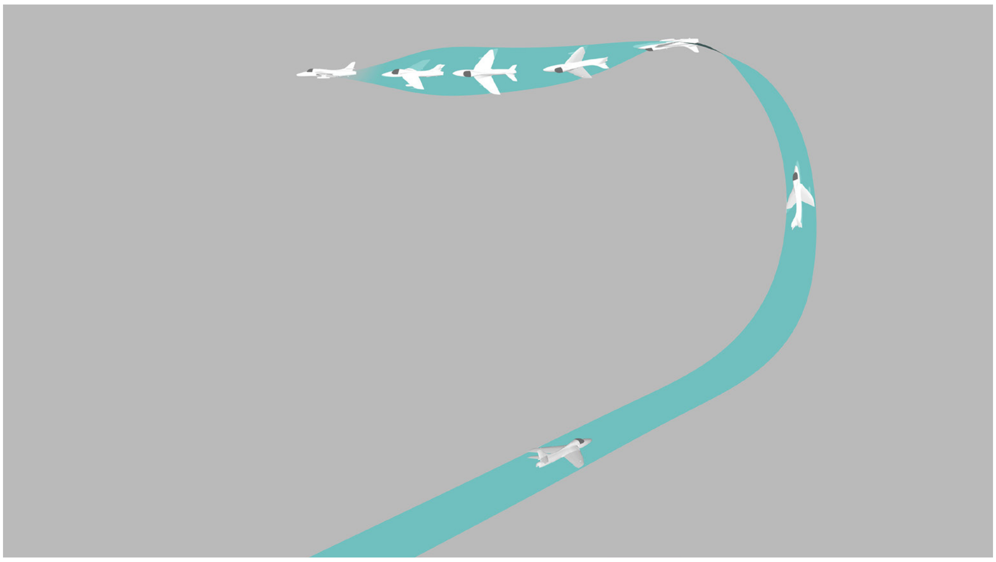

Figure 24

Illustration of a rolling escape manoeuvre

If the height at the apex of the loop is less than the gate height, the stick is moved forward to stop the pitch rate and the aircraft is then rolled through 180°, with the wing unloaded, and then recovered from any descent and returned to level flight.

1.18.3.5 Manoeuvres analogous to escape manoeuvres

The TP made the following observations concerning the relationship between an escape manoeuvre and manoeuvres the pilot may have conducted previously, such as a half Cuban 8.

> *'There are several manoeuvres flown in many aircraft types that, upon initial consideration, may appear to be analogous to an escape manoeuvre flown at the apex of a loop during low level aerobatics. The criteria that determine the validity of the analogy are the cues and parameter values that a pilot uses, the airspeed existing when the roll is performed and the precise, detailed control strategy that is subsequently employed. Below is a description of these aspects for an escape manoeuvre and the relevant differences for other manoeuvres which may be considered analogous.*

> ***a. Escape manoeuvre*** *In a looping manoeuvre flown at an air display, the pilot will have visual cues available throughout and therefore should have continual awareness of the aircraft's attitude. At the apex (usually assessed from a pitch attitude comparison against the visual horizon and then confirmed by altimeter indication rate of change being zero), the cue for deciding whether or not to continue with the looping manoeuvre or to perform an escape manoeuvre will be an altimeter reading which is then compared to a known 'gate height'. Sometimes, there may also be a secondary airspeed consideration even if above the gate height (normally a maximum airspeed and applicable to manoeuvres such as a reverse Cuban 8 or vertical 8). The decision to fly an escape manoeuvre will be made in a near level, inverted attitude. If airspeed is low, the pitch rate may be maintained until in a shallow dive before continuing with the escape manoeuvre. The control strategy in a Hunter is then to reduce the pitch rate to zero (to reduce the amount of nose drop whilst rolling and to reduce angle of attack and thus any departure tendency) and then to roll gently to wings level whilst restraining the rudder at neutral. The aircraft is then pitched nose up to regain level flight.*
>
> ***b. 1/2 Cuban 8*** *In this manoeuvre the fundamental difference to an escape manoeuvre as described above is that the loop is continued until on a down 45° line before the pitch rate is stopped and the roll to erect flown. The airspeed when the roll is commenced will be significantly greater than at the apex and will be increasing, and elevator and/or rudder inputs are used to maintain a straight flightpath on the down 45° line. It is possible to fly an escape manoeuvre in this manner but that is the extreme nose down pitch attitude that would be used rather than the norm. The fundamental differences to an escape manoeuvre as described above is that the airspeed will be significantly greater in a 1/2 Cuban 8 and that elevator and rudder inputs will be made to control the flightpath.'*

1.18.3.6 Other observations

A loose article was seen on the video during the aerobatic sequences at both the Duxford and Shoreham displays in 2014. During the Duxford 2014 display, an A5 size document fell into the cockpit canopy the first time the aircraft became inverted. It then fell down into the cockpit when the aircraft was rolled upright as part of the manoeuvre being undertaken. It did not reappear during the remainder of the display.

During the Shoreham display in 2014, the pilot was wearing an action camera attached with Velcro to the right side of his flying helmet. During the first rolling manoeuvre the helmet communication lead became caught over the camera and, during the roll to the upright, the lead pulled the camera from the helmet causing it to fall down into the cockpit. It did not reappear during the remainder of the display. The pilot was not seen to recover either loose object and both this display and the display at Duxford continued.

CAP 403, Paragraph 5.19, *'Pre-flight inspection'*, stated:

> *'The normal pre-flight inspection is to be carried out with special emphasis on the following areas':*
>
> *Item c) 'Thorough check for loose objects in the cockpit and elsewhere in the aircraft.'*

CAP 403 also draws attention to the hazard of *'loose articles in the cockpit'*.

The operator's OCM did not contain any requirements or guidance on loose articles or fitting of action cameras. With no formal SMS, and relying on informal regular contact between the operator's two pilots, both loose article incidents went unreported and the Chief Pilot was unaware of them.

1.18.4 UK flying display statistics

1.18.4.1 Fatal accidents at UK flying displays 1996-2015

Table 8 lists fatal accidents at UK flying displays between 1996 and 2015, showing the total flying hours and hours on type of the pilot in each case. The figure is clustered by location (within or outside the area controlled by the display organiser).

	Date	Reg'n	Type	Location[1]	What happened	Total hours	Hours on type
1	22/08/2015	G-BXFI	Hawker Hunter	Outside	Insufficient height to complete looping manoeuvre	14,249	43
2	01/08/2015	G-TIMM	Gnat	Outside	Loss of control rolling manoeuvre	706	218
3	19/06/2010	G-DUKK	Extra 300	Outside	Did not recover from spin manoeuvre with sufficient height	3,600	70
4	15/09/2007	G-HURR	Hawker Hurricane	Outside	Loss of control during rolling manoeuvre	1,115	186
5	31/05/2003	ES-XCL	Spirit of St Louis Replica	Outside	Structural failure of wing	21,200	190
6	02/06/2001	G-DHAV	DH 115 Vampire	Outside	Loss of control in wake vortex	4,398	185
7	21/07/1996	G-ASKH	DH 98 Mosquito	Outside	Loss of control in rolling manoeuvre, engine issue	10,395	72
8	11/07/1996	N3145X	P-38 Lightning	Outside (initial impact on airfield)	Loss of control in rolling manoeuvre	14,500	60
9	01/07/2012	G-EBHX[2]	DH 53 Hummingbird	On airfield	Loss of control in gusty conditions	14,780	0.9
10	03/07/2001	G-BTWR	Bell King Cobra	On airfield	Loss of control in vertical manoeuvre	7,730	13
11	18/08/2000	G-MAYA	L29 Delfin	Offshore- in MEZ[3]	Did not recover from vertical manoeuvre	18,222	235
12	09/08/1998	G-BIVZ	Druine Turbulent	On airfield	Loss of control, stalled in formation	784	219
13	04/06/1996	G-FLYV	Slingsby	On Airfield	Did not recover from vertical manoeuvre	3,675	2,500

Table 8

Fatal accidents[38] at UK flying displays 1996-2015

Table footnotes:

1 In relation to area controlled by display organiser.

2 The accident to G-EBHX occurred during a display practice at a time when the display crowd was present and the provisions intended for the flying display were in place.

3 Maritime Exclusion Zone.

38 The accident to G-BXFI was the only fatal accident in this table in which members of the public were also fatally injured.

Table 9 lists the other UK civil flying display-related accidents in this period, identified by the AAIB. It excludes the accidents involving engine failure where damage was sustained during the subsequent forced landing.

No	Date	Reg'n	Type	Location	What happened	Total hours	Hours on type	Worst injury
14	22/04/ 2015	G-EDGJ	Edge 360	Outside (Practice)	Did not recover from vertical manoeuvre	1,290	265	Fatal
15	27/04/ 2013	G-CHFS	Replica Fokker EIII	On Airfield (Practice)	Loss of control rolling manoeuvre	1,903	10	Fatal
16	10/07/ 2012	G-BZGK	North American OV-10 Bronco	Outside (Practice)	Loss of control, rolling manoeuvre	4,096	179	Serious
17	10/07/ 2011	D-FBBD	Mustang	Outside (Display)	Mid-air collision	3,894	1035	Minor
18	22/08/2010	G-IZII	Swift Glider	On Airfield (Display)	Loss of control during landing	473	57	Serious
19	21/07/2002	G-AKXS	Tiger Moth	On Airfield (Display)	Loss of control	14,481	280	Serious

Table 9

Selected other UK flying display-related accidents 1996-2015

The flying experience of display pilots involved in fatal accidents during flying displays in this period ranged from 706 hrs to 21,200 hrs.

1.18.4.2 UK flying display accidents where the aircraft crashed in the area below its display

Fourteen of the nineteen listed UK display and display practice-related accidents have occurred where control of the aircraft was lost, or structural failure occurred, and it subsequently impacted the surface beneath the manoeuvring area. Table 10 identifies those in the twenty years to 2015:

Year	Registration	Display / Practice	Fatalities
2015	G-BXFI	Display	Yes
2015	G-EDGJ	Practice	Yes
2013	G-CHFS	Practice	Yes
2012	G-BZGK	Practice	No
2012	G-EBHX	Display	Yes
2010	G-IZII	Display	No
2010	G-DUKK	Display	Yes
2007	G-HURR	Display	Yes
2003	ES-XCL	Display	Yes
2001	G-BTWR	Display	Yes
2000	G-MAYA	Display	Yes
1998	G-BIVZ	Display	Yes
1996	N3145X	Display	Yes
1996	G-FLYV	Display	Yes

Table 10

Display accidents involving impact beneath the manoeuvring area

1.18.4.3 Accident rates at flying displays

The CAA estimated that the overall UK general aviation fatal accident rate between 2005 and 2014, including display flying, was approximately 1.3 fatal accidents per 100,000 flying hours[39]. It does not define a target acceptable level of safety for UK flying displays, and it does not monitor the accident rate for display flying, the number of display items or the number of hours flown by civil display aircraft in any year.

CAA records show that in 2015 there were 254 '*Article 162 permissions*' granted. These included approximately 1,480 individual civil display items[40].

There were two fatal accidents at organised displays in 2015. Considering a longer period, and assuming the planned 2015 activity was typical, there has been 1 fatal accident per 2,960 display items in the period 2008 to 2015[41].

39 CAP 1284 – '*Public consultation: UK Private Pilot Licence and National Private Pilot Licence medical requirements*', published May 2015, Figure 2. CAP 1284 does not specify the date range for this figure.

40 This included 1,730 items approved at civil displays minus approximately 250 UK military items at civil air displays. It was not possible to correct for foreign military or items approved but which did not perform due to weather, technical failure or other reasons.

41 This period was chosen to coincide with relevant data available from the USA, which was of sufficient detail to enable the number of fatal accidents to be extracted, distinct from the total number of fatalities caused.

The International Council of Air Shows, the flying display industry body in the USA and Canada, estimated that in the USA the civil flying display accident rate is 1 fatal accident per 5,600 display items.

Between 1996 and 2015 more than half of UK display accidents involved the aircraft crashing outside the area controlled by the organisers of the display. This equates, at 2015 levels of activity, to one display aircraft crash in an area accessible to the public every 2.2 years.

Aircraft involved in UK flying display accidents between 1996 and 2015 crashed at varying distances from the areas controlled by the display organisers. The most distant was 2,000 m from the closest point on the aerodrome, following a mid-air collision with the aircraft on an upward trajectory.

1.18.4.4 Scale of UK flying displays in 2015

Based on the available CAA records, the approximate scale of activity at UK civil flying displays in 2015 is set out in Table 11. An 'item' may involve more than one aircraft, for example in the case of a formation display. Half the Article 162 permissions were for a single display item and 84% involved less than seven items[42].

Number of display items	Number of displays
Single display item	126
2 to 6 acts	87
7 to 15	24
16 to 20	11
21 or more	6
30 or more	Nil

Table 11

Article 162 display permissions by size 2015

1.18.4.5 UK flying display activity in 2015, by month

UK flying displays occur mostly at the weekends between May and September (see Figure 25 and Figure 26). As an example, in different parts of the UK, on 11 July 2015 there were 16 Article 162 permissions in effect.

42 Displays of seven or more items require a Flying Control Committee.

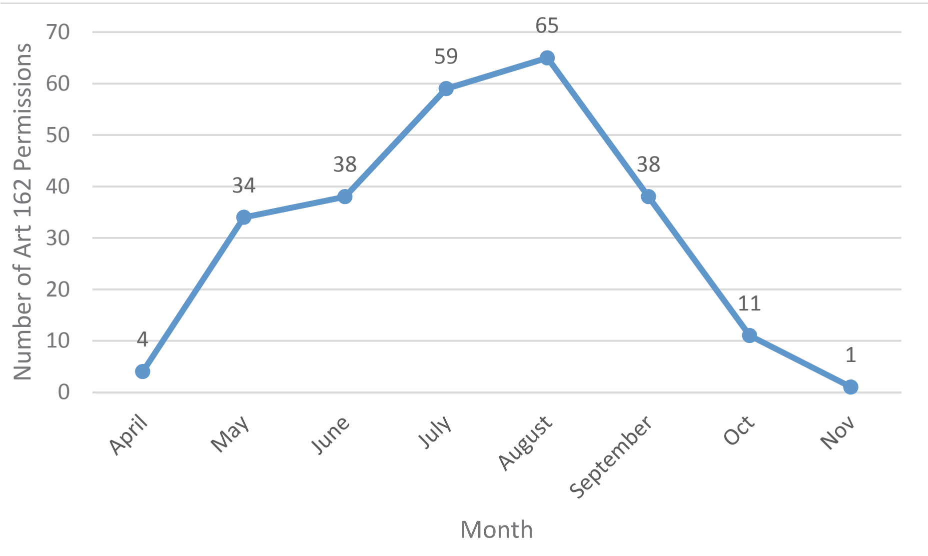

Figure 25

Number[43] of approved flying displays in the UK per month in 2015

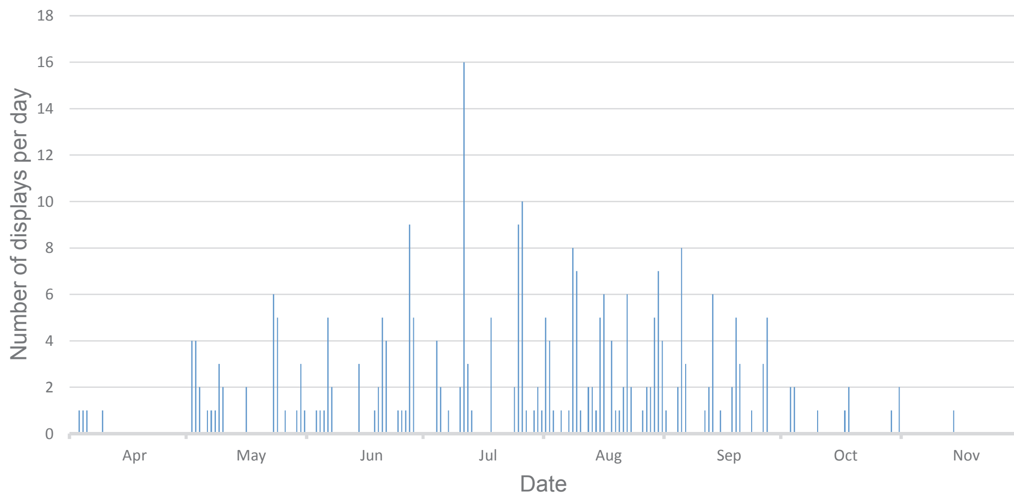

Figure 26

Distribution of flying displays in the UK in 2015 by month

43 A single permission can cover a flying display held over more than one day.

1.18.4.6 Other aircraft accidents in the UK involving third-party fatalities

The AAIB used the CAA's database of mandatory occurrence reports to search for aircraft accidents involving third-party fatalities in the 40 year period from 1976[44] to 2015. Accidents involving persons being struck by propellers or rotors during ground operations were excluded as were two accidents involving helicopters operating under Air Operator Certificates. Four accidents were identified and are shown below:

Date	Type	Details	Third-party fatalities
09/08/2005	Glider	Descended outside airfield during racing finish; struck photographer	1
03/07/1998	Glider	Normal landing; struck pedestrian on public right of way which crossed runway	1
30/04/1987	Cessna 172	Loss of control in flight, struck and destroyed yacht	2
28/09/1985	Gemini Microlight	Loss of control on takeoff from public fete; struck group of spectators	1 (7 injured)

Table 12

Other UK aircraft accidents involving third-party fatalities

1.18.5 Monitoring of safety standards at flying displays

1.18.5.1 CAA staff competencies and resources

In 2015 the CAA GAU had two flying display inspectors known as Operations Flight Standards Officers (FSO). A document provided by the CAA, dated 20 October 2014, described the role of a FSO as including:

> *'…undertaking specific inspecting audit and oversight tasks…to ensure effective and proportionate on-going oversight of the GA activity meets agreed safety and performance standards'…*

It listed the *'principal accountabilities'* of an FSO, including:

> '• *Prepare and issue Permissions, Exemptions, Approvals and Variations in area of allocated responsibilities.*

44 The database began in 1976. The CAA stated that in a ten year period from 2006-2015 there were no aircraft accidents involving third-party fatalities other than that involving G-BXFI. This information is included to show that the total recorded number of aircraft accidents involving third-party fatalities is not large.

- *Conduct Inspections and Audits in area of allocated responsibilities including Flying Displays, Ex-Military Aircraft Operators, Model Aircraft and Parachuting to establish that operators are compliant with the legislative requirements and to establish an assessment of risk for each operator.*
- *Provide expert input into the regulation of the UK General Aviation Industry to support the GA Unit policy of developing proportionate and performance based oversight to encourage a vibrant GA industry within the UK.*
- *Identify and develop amendments to CAPs and guidance material to keep it up to date with technical and legislative changes.'*

It listed the knowledge and experience required of an FSO, as follows:

'• *Must hold or have held a private or professional pilot [licence] (or military equivalent), or have current substantive authority and industry regulatory experience that provides an equivalent level of knowledge required for the job role.*
- *Must have or* [have] *held a UK CAA Display Authorisation.*
- *Must have thorough knowledge of all aspects of aircraft operations gained through appropriate flying experience, or through authority and industry regulatory experience.*
- *Must be able to communicate verbally and in writing to a high standard.*
- *Must be able to utilise project management disciplines to ensure assigned work is managed to agreed criteria of cost, time and quality.*
- *Must be able to understand and analyse complex technical data.'*

Both of the FSO's held current UK DAs.

One of the FSOs in the CAA GAU had conducted inspections and audits of Article 162 displays and CAP 632 organisations for five years. According to his training records he had received formal training in conducting audits in November 2014. The other FSO's training records did not show any formal training in the conduct of audits. He had attended a course entitled *'Advanced Safety Management – Evaluating for Effectiveness'* provided by CAA International Services between 23 and 24 March 2015.

1.18.5.2 UK Display inspections

CAP 403 states:

> *'The CAA GA Unit is required to inspect and monitor safety standards at a number of events annually.'*

On 28 October 2015 the CAA published CAP 1351 - *'CAA Review of Civil Air Displays: progress report'*, which stated that:

> *'CAA experts visit a significant number of air displays each year to:*
>
> - *monitor safety standards*
> - *confirm the rules are being complied with*
> - *identify measures that might further enhance safety standards'*

The CAA's 1996 Review stated that:

> *'The Authority had conducted 37 display inspections during 1996 and it was intended to maintain that level of inspection for the 1997 season…it was considered that an acceptable level of safety monitoring in this regard will occur.'*

The CAA informed the AAIB that in 2014 it gave permission for 281 displays and inspected eight[45] of them (2.8%).

In 2015 the CAA attended 18 of the 254 displays (7%), including six displays following the accident to G-BXFI some of which were attended by non-specialist staff.

In Special Bulletin S1/2016 the AAIB stated that in the USA, regulatory staff of the Federal Aviation Administration (FAA) attend every authorised display[46]. The FAA states that:

> *'The inspector's responsibility is to provide adequate safety oversight of the aviation event and to ensure compliance with the provisions of the waiver or authorization.'*

The CAA stated that it considers the FAA has a different role in relation to air displays, with a different approach and funding model.

45 At the time of publication of Special Bulletin 1/2016 the CAA had located the inspection reports for five displays (including a model aircraft flying display), and therefore was reported as having attended four (1.4%). Subsequently the CAA located four additional inspection reports that had not been entered into its computerised systems. Accordingly, the AAIB now understands that the CAA inspected eight displays in 2014.

46 The FAA occasionally waives this requirement, in specific circumstances, generally for fewer than 10 events each year.

1.18.6 Separation between the primary crowd and displaying aircraft

CAP 403 states the minimum separation distances required between the crowd line and relevant display line based on the speed of the displaying aircraft. At the time of the accident these separation distances had not changed for several years[47].

The accident to G-BXFI did not involve the primary crowd and its separation from the display aircraft. Nevertheless, as part of its investigation into the separation of the public from the consequences of a loss of an aircraft, the AAIB requested that the CAA provide it with the information supporting the current arrangements.

The CAA commissioned a study, published in 1993, (referred to here as the 1993 Study[48]) to assist it in determining if the existing distances specified in CAP 403 were appropriate.

The 1993 Study considered a structural failure, during a display flight, of two different aircraft types: a fast jet travelling at 350 kt and a single piston-engined aircraft travelling at 100 kt.

Computer modelling predicted the distance that debris from the aircraft would travel until it reached a height of 5 feet above the surface. The modelling assumed that each aircraft was making a level, 4g turn onto its respective display line, separated from the crowd by the relevant distance shown in CAP 403.

The 1993 Study showed that in the circumstances considered, and for both types of aircraft, substantial pieces of wreckage such as engines would cross the crowd line. In the case of the fast jet aircraft it was predicted that the engine(s) would enter the crowd area by at least 130 m.

The 1993 Study concluded that:

> '*The current issue of CAP 403, 'Flying Displays: A Guide to Safety and Administrative Arrangements', reference 2, includes regulations concerning minimum crowd line to display axis distances that are well judged and for the majority of conditions appear to offer a sensible compromise between airshow attractiveness and safety.*'

47 The distances have been amended following this accident and are subject to further review.
48 Airshow Separation Distances, Cranfield Aviation Safety Centre, July 1993.

Since the study there have been advances in both technical modelling capability and in the understanding of managing risk to the public.

The accidents considered in the study had low probability but significant consequences. The study showed that display separation distances still being specified in 2015 offered no greater protection of the primary crowd than during the 1952 Farnborough Airshow accident[49].

1.18.7 Non-participant third parties and secondary crowds

1.18.7.1 A27 vehicular traffic

Figures from the Department for Transport show that on average 58,500[50] vehicles use the A27 between the junctions of the A2025 and the A283 daily. This section of road includes the area to the north of Shoreham Airport where the accident occurred.

By comparison, a section of motorway that passes another popular UK display site is used by an average of 40,302[51] vehicles per day.

The organisers of the Shoreham Airshow informed the AAIB that, several years previously, they had discussed closure of the A27 with relevant parties but had been told it would be impossible to close such an important road for the event.

Highways England informed the AAIB that mechanisms existed to close major roads such as the A27 for large events, for a few minutes at a time or longer, and that it would consider any case proposed by an event organiser on the basis of risk, cost and benefit. Highways England did not receive a request in relation to the 2015 Shoreham Airshow and it did not comment on what its decision might have been had the organisers done so.

1.18.7.2 Secondary spectators

The FAA uses the phrase ‘secondary spectator areas’ in its display regulations regarding the protection of persons who decide to watch an event away from the official crowd.

49 On 6 September 1952 a DH110 prototype fighter aircraft broke up in flight while being demonstrated at the Farnborough Airshow. Parts of the aircraft entered the crowd, injuring 31 fatally.
50 Figures for 2014, the latest year for which they were available.
51 Figures for 2015, the latest year for which they were available.

These are defined in Section 33 of the FAA FSIMS[52] 8900 as follows:

> *'Secondary Spectator Areas: Any area, not designated as a primary spectator area, where people have a natural tendency to gather to observe the event. This includes, but is not limited to, private property or property not under the control of the event organizer, public roads and private access roads.'*[53]

FSIMS requires display organisers to put in place minimum separations and overflight conditions in relation to these areas.

CAP 403 highlights that secondary spectator areas should be discouraged by the display organisers but does not put in place specific protection for them. However, it states:

> *'At many events, particularly at airfield sites, the congregation of spectators, outside the airfield boundary, on the live-side, may give organisers cause for concern.* […] *It is recommended that the event organiser anticipates this during the planning process and takes necessary steps to reduce it by, where possible, blocking the view from obvious vantage points.'*

The organisers of the 2015 Shoreham Airshow had identified that the junction of the A27 was a popular location from which to view the display. The AAIB was informed that in previous years several hundred people had been observed at the road junction between the A27, Shoreham Bypass, and the Old Shoreham Road, and in the grounds of a nearby, now closed, public house. The display organisers and the local emergency services had been concerned about the road traffic risk to these crowds and the display organisers had taken steps to minimise the number of people in this area.

The ground operations risk assessment identified the hazard as, '*Fast moving trunk road. 70 mph dual carriageway Traffic lights and queuing traffic.*' and proposed the action as '*Traffic management plan in place. No right turns. Traffic Lights off and 40 mph limit in place.*'

The arrangements, which had been in place for several years, included restricting the view of the airfield, placing signs in the area and having stewards ask people to move on. However, neither the organisers nor the police had requested or been granted the power to exclude people from this area and their efforts did not prevent a gathering at the A27 junction.

52 Flight standards information management system.
53 Unlike the primary crowd area permission may be given for display aircraft to overfly the secondary crowd area if at height of more than 500 ft with wings-level and climbing.

1.18.7.3 Other non-participant third parties

CAP 403 requires display organisers to consider:

> *'The proximity of congested areas, particularly if they include schools or hospitals.'*

Approximately 40% of the surface area, within 2 km of Shoreham Airport, encompasses residential, industrial and recreational parts of settlements, the A27, a rail route and the buildings of Lancing College (Figure 27).

Figure 27

2 km radius of Shoreham with congested and high density areas shown in grey

There is a large fuel storage facility within an industrial site, located 500 m from the north-east end of the display line, which it is estimated can contain up to 600,000 ltr of road vehicle fuels.

Some of these areas were marked on the display map showing overflight restrictions (see Figure 8).

AAIB Special Bulletin S1/2016 described that both the FAA and Transport Canada require flying display-related aerobatic flight below normal heights[54] to be conducted within a designated volume of airspace, known in Canada as a 'flying display area' or in the USA as an 'aerobatic box' .

54 The FAA prohibits aerobatic flight below 1,500 ft agl, Transport Canada prohibits aerobatic flight below 2,000 ft agl outside such a volume of airspace.

1.18.8 Previous Safety Recommendation

On 15 September 2007, a Hawker Hurricane, G-HURR, crashed while taking part in a flying display at Shoreham Airport. AAIB Aircraft Accident Report 6/2009, concerning this accident, contained six Safety Recommendations. Safety Recommendation 2009-052 stated:

> *'It is recommended that the UK Civil Aviation Authority requires that the sequence of manoeuvres for a flying display is clearly specified in advance of the display and provided to the display organiser and that the sequence is practised prior to displaying to the public.'*

On 20 October 2009, the CAA published a FACTOR F10/2009 in which it gave its response to the Safety Recommendation, as follows:

> *'The CAA accepts this Recommendation in so far as, since the start of the 2008 display season, it has been a requirement for both display pilots and display organisers that any large formation or set piece display must have been specified prior to the display. The requirement to practice the display sequence is already covered in CAP 403, CH 6, para 5. However it is believed to be impractical to require that individual civilian display pilots specify a display sequence prior to the display and are then not allowed to vary it or modify it in any way later. Circumstances and weather conditions on the day of the display, such as time pressure in the display programme and wind strength, may make it safer to vary a display, for example by moving one or more manoeuvres from the approved sequence or by flying a flat display, rather than adhere strictly to the display originally specified.'*

The FSOs in post at the time were actively involved in display flying and, like some others in the flying display community, were opposed to accepting Safety Recommendation 2009-052. However, following discussions within the CAA and with members of the flying display community, the then Head of Flight Operations decided that the Safety Recommendation should be accepted and implemented. His decision was recorded and reported in a second FACTOR issued on 9 April 2010, revising the response of 20 October 2009:

CAA Response

> *'The CAA accepts the Recommendation. CAP 403 (Eleventh Edition – dated 1 April 2009) requires that:*
>
> *a. the flying display director during the planning phase of the event will be required to consider and manage pilot display programmes.*
>
> *b. the Flying Display Director ensures that pilots do not carry out any form of impromptu display.*
>
> *c. participants remain aware that the impromptu, ad hoc, unrehearsed or unplanned should never be attempted.*
>
> *d. the Flying Display Director is charged with circulating, prior to the event a written brief to all participants which will include details of manoeuvres to be flown at the event that are known and have been practised (including bad weather 'flat shows').*
>
> *e. pilots are required to have flown or practised at least three full display sequences (at least one of which was flown or practised on the aircraft type to be utilised in the display) in the 90 days preceding the event.*
>
> *f. on the day of the event, no pilot may take part in the event unless he has participated in the formal Flying Display briefing, either in person or telephonically (if he is not landing at the flying display site).'*

In this response the phrase 'pilot display programmes' appears to have replaced 'sequence of manoeuvres' specified in the Safety Recommendation, and it is not clear if it was intended to address the same issue. The FDD of the 2015 Shoreham Airshow did not know the sequence of manoeuvres intended to be flown by the pilot of GBXFI, and CAP 403 did not indicate that he should.

1.18.9 Minimum heights

1.18.9.1 Authorised display heights

A pilot's DA states the minimum height at which the holder may fly during a display. The CAA commented that this is intended to be an absolute minimum, not a target, and that the pilot must comply with the normal rules of the air[55] when not on the display line. Consequently, depending on the aircraft type and length of the display line, the minimum height listed on the pilot's DA might not be achievable over the entire length of the display line, if at all.

55 This report refers to 'normal rules of the air' as those that apply other than at flying displays.

1.18.9.2 Application of minimum heights

Part 33 of the ANO, *'Interpretation'*, defines aerobatics as:

> *'Aerobatic manoeuvres' includes loops, spins, rolls, bunts, stall turns, inverted flying and any other similar manoeuvre.'*

The report of the CAA's *'United Kingdom Civil Air Display 1996 Review'*, published on 22 April 1997, stated at Section 3.6.3 that:

> *'Pilots whose DA included an aerobatic approval were cleared to perform aerobatic manoeuvres to a specified base height. The DA might also include a fly-by height lower than the aerobatic manoeuvre base height. It was noted that it had become common practice for pilots to use their fly-by height in the middle of an aerobatic sequence, provided they had completed the aerobatic manoeuvre by the specified base height. There was some concern that such an interpretation could lead to subsequent aerobatic manoeuvres being commenced from the wrong datum.'*

Following the accident to G-BXFI, the CAA introduced an enhanced risk assessment process. The AAIB was provided with the results of this process for some sites. In it the CAA assessor referred to 'normal rules of the air' applying away from the display line as a mitigation related to aircraft overflying roads. The risk assessment for the 2015 Shoreham Airshow identified 'compliance with the Rules of the Air' as a mitigation for the hazard of an 'Aircraft Crash Outside the Airfield Boundary'. The information provided indicated that the CAA, and the Shoreham FDD, assumed pilots would only descend to their approved minimum height over the display line, and the Shoreham risk assessment appeared to rely on this to manage the risk associated with flight at low heights during the flying display.

1.18.9.3 Standardised European Rules of the Air

European Union Regulation 923/2012 issued on 26 September 2012 sets out the Standardised European Rules of the Air (SERA). Section 3, paragraph 3105 '*Minimum heights*' states:

> *'Except when necessary for take-off or landing, or except by permission from the competent authority, aircraft shall not be flown over the congested areas of cities, towns or settlements or over an open-air assembly of persons, unless at such a height as will permit, in the event of an emergency arising, a landing to be made without undue hazard to persons or property on the surface. The minimum heights for VFR flights shall be those specified in SERA.5005(f).'*

Section 5 paragraph 5005(f), requires aircraft under Visual Flight Rules (VFR) to be at minimum heights of either 500 ft or 1,000 ft depending on other conditions[56].

The European Aviation Safety Agency '*Acceptable Means of Compliance (AMC) and Guidance Material to the Rules of the Air*' published in July 2013 state:

> *'The permission from the competent authority to fly at lower levels than those stipulated in SERA.5005(f) and SERA.5015(b) may be granted either as a general exemption for unlimited number of cases or for a specific flight upon specific request. The competent authority is responsible for ensuring that the level of safety resulting from such permissions is acceptable.'*

1.18.9.4 CAA exemption from SERA 5005(f)

On 13 August 2015[57] the CAA, as the competent authority in the UK, issued '*Official Record Series 4-1124*' (ORS4-1124) relating to SERA. It stated in paragraph 4:

> *'Flying Displays, Air Races and Contests*
>
> *The Civil Aviation Authority permits, under SERA.3105 and SERA.5005(f), an aircraft taking part in a flying display, air race or contest to fly below 150 metres (500 feet) above the ground or water or closer than 150 metres (500 feet) to any person, vessel, vehicle or structure if it is within a horizontal distance of 1,000 metres of the gathering of persons assembled to witness the event.'*

The EASA AMC requires the competent authority to ensure that the resulting level of safety is acceptable. The CAA has not provided any risk assessments or other relevant documentation to support its decision to issue the exemption, but stated:

> *'Rule 5 and Rule 6 of the Rules of the Air Regulation 2007 were the relevant rules in place in the UK prior to the publication and implementation of the SERA rules. These rules had been in place since at least 1996 and there was no evidence to suggest that these rules were inherently unsafe.'*

56 SERA 5005(f) states: Except when necessary for take-off or landing, or except by permission from the competent authority, a VFR flight shall not be flown: (1) over the congested areas of cities, towns or settlements or over an open-air assembly of persons at a height less than 300 m (1 000 ft) above the highest obstacle within a radius of 600 m from the aircraft; (2) elsewhere than as specified in (1), at a height less than 150 m (500 ft) above the ground or water, or 150 m (500 ft) above the highest obstacle within a radius of 150 m (500 ft) from the aircraft.

57 Although the ORS exemption was issued in August 2015 this continued a previous UK derogation from the EU standards.

In August 2005 a glider (BGA 4665), involved in an air race in Leicestershire, struck and fatally injured a person standing outside the boundary of the aerodrome at which it was operating. The AAIB report[58] stated:

> *'…the root cause was the practice of flying too low outside the confines of the airfield and resorting to pop-up manoeuvres to clear obstacles.'*

Five Safety Recommendations were made, including the following:

> **Safety Recommendation 2006-120**
>
> The Civil Aviation Authority should clarify and publicise whether permission from the Authority is required before exemption from the 500 feet low-flying rule in accordance with Rule 5 (3)(f) is applicable.

In an interim response, in April 2007, the CAA indicated that it accepted this Safety Recommendation stating:

> '…*the CAA intends to change Rule 5 (3)(f) as it is unsatisfactory in its present form*.'

However, Rule 5(3)(f) was not changed until superseded by the SERA, and the permission in ORS4-1124 has the same effect as Rule 5(3)(f).

1.18.9.5 SERA implementation

Between 2008 and 2012, Eurocontrol led the development of SERA. Part A was the first phase and transposed ICAO Annex 2. Part B involved the Rules of the Air and was EASA led. Member States and industry were consulted. The European Commission decided not to introduce Part A but merge it with Part B. The SERA took effect on 12 December 2012 but there was a derogation period until December 2014 during which member states did not have to apply SERA and during which the CAA carried out a full UK consultation in 2013, for which a 12 week period was allowed. The CAA produced a paper, dated 9 May 2013, entitled '*Standardised European Rules of the Air – UK implementation*', in which, on page 6, a timescale for completing the process was set out. There was some deviation from this timescale but this was mainly due to a rewrite of the ANO, and the CAA were exempted from implementation until April 2015. The ANO revision was centred on the progression of ANO Rules of the Air being aligned with SERA to remove duplication and ensure consistency.

58 Glider BGA 4665, published in AAIB Bulletin 2/2007.

The then Chairman of the CAA SERA implementation working group was unaware of the accident to the glider referred to earlier, the associated AAIB Safety Recommendation and the CAA's intention to change Rule 5 (3)(f). No comment was made in the SERA consultation report relating to this issue and therefore the Permission was retained.

The AAIB made the following Safety Recommendation in Special Bulletin S1/2016 following the accident to G-BXFI:

> **Safety Recommendation 2016-036**
>
> It is recommended that the Civil Aviation Authority remove the general exemptions to flight at minimum heights issued for Flying Displays, Air Races and Contests outlined in Official Record Series 4-1124 and specify the boundaries of a flying display within which any Permission applies.

The CAA first responded to Safety Recommendation 2016-036 in FACTOR F4/2016, issued on 9 June 2016, removing Official Record Series 4-1124. It updated its response in FACTOR F4/2016 Issue 2, as follows:

> *'The CAA has removed the general exemption to flight at minimum heights issued for civil air displays, air races and contests, outlined in Official Record Series 4-1124.*
>
> *Display Permissions granted by CAA under Article 86 of the Air Navigation Order 2016 now specify the boundaries of a flying display within which the permission applies.'*

1.18.10 Human factors

1.18.10.1 Physiology

The AAIB considered whether subtle incapacitation by g forces could have reduced pilot performance during the left turn prior to the pull-up into the accident manoeuvre. The actual g experienced is not known because the cockpit g-meter was not functioning, but a study of the available data by the Royal Air Force Centre of Aviation Medicine (RAFCAM) concluded that a high g load was not present at any point in the left turn preceding the entry to, or in the upward half of, the accident manoeuvre. The peak g force calculated for the turn was 2.7 g and, whilst g tolerance varies, it was considered unlikely that the pilot was either partially or totally incapacitated by g forces immediately prior to commencing the accident manoeuvre.

The Consultant in Aviation Medicine (RAF) concluded:

> *'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[59] or A-Loc[60] syndromes, and the G levels in the accident video are similar to previously experienced levels flown without incident (eg in the Duxford video). Therefore, I can find no evidence of G related impairment in the material available for review.'*

The available information did not support an accurate assessment of the peak g force during the accident manoeuvre. As far as could be determined from cockpit image recordings the pilot appeared alert and active throughout the flight.

1.18.10.2 Study of human performance

The investigation commissioned a study by the RAFCAM of human factors (HF) that may have contributed to the accident.

The study focused on the accident manoeuvre. The aim of the analysis was to understand the scope for human actions and decisions that may have contributed to the accident sequence. Its report refers to the 'AAIB Operations Advisor', who was the TP conducting the flight trials and assisted with other aspects of the investigation.

A task analysis and human error analysis considered two points in the manoeuvre:

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

The study aimed to identify which factors affected the following four phases of the hazard sequence:

- Hazard entry. - The probability the aircraft would enter a hazardous scenario;
- Recovery. - The probability that the aircraft would successfully recover;

59 G-induced loss of consciousness.
60 Acceleration-induced near-loss of consciousness or "almost loss of consciousness".

- Escape. - The probability of the pilot escaping without injury; and
- Survival. - The probability of personnel surviving.

Entry to the accident manoeuvre

The study considered that the pilot's primary decision for entering the manoeuvre was to assess if the aircraft had achieved a minimum of 350 KIAS, which for a minimum height loop was also a target speed. In the 30 seconds prior to entering the accident manoeuvre, cockpit imagery indicated that the pilot looked down towards the instrument panel four times, suggesting he was actively gathering information. Whilst it is not known if he read the ASI, given that 350 KIAS was his entry gate, it would be reasonable for him to be checking it approaching the pull-up point.

It was also important for the pilot to ensure that his entry into the manoeuvre was close to the display line but not too close to the spectators that he would infringe the crowd line. This meant important dual tasks being undertaken splitting his attention between the two. Information gathering has limitations, especially during high workload when activities such as scan pattern, locating the correct instrument, allocation of attention, change blindness, distraction, or visual limitations such as contrast and glare can have significant effects on the accuracy of the information gathered. High workload and distraction reduce the available cognitive resources and so increase the likelihood of error.

The entry speed was 310±15 KIAS, which was below the stated target. The study identified the following possibilities for his decision making process:

- He did not read the ASI but believed he had and simply entered the manoeuvre, concentrating on positioning and flying technique.
- He misread the ASI due to the display of the instrument, high workload or distraction of judging the pull-up point.
- He read the ASI correctly and elected to enter the manoeuvre and adjust his technique to achieve a height at the apex that would allow him to pull through.
- He read the airspeed correctly but incorrectly recalled the entry speed as 300 KIAS.

The pilot stated that he would use maximum thrust from the point of entry to the apex. Had this been set, the aircraft could have reached a safe apex height even with the lower entry speed that was achieved. The reduced thrust used was either selected by the pilot (intentionally or inadvertently) or the result of an engine malfunction. The use of less than maximum thrust was not a technique he used consistently on the Hunter or Jet Provost. The TP explained the difficulty in detecting reduced thrust during the 'up vertical' part of the manoeuvre, and given the pilot's focus on external cues, if it was not selected by him he was probably unaware of it. The main indicators of a reduction in thrust at the apex would have been the low height (2,700 ft) and low airspeed (approximately 105 kt).

The apex of the accident manoeuvre

The pilot stated that he required a minimum height of 3,500 ft to pull through and not descend below his minimum authorised height for aerobatics of 500 ft. His declared gate height for the manoeuvre was 4,000 ft, which included an extra 500 ft margin. He expected to see an airspeed of approximately 150 KIAS at the apex.

The pilot's head movements approaching and at the apex were mainly directed outside the cockpit but he appeared to look at the area of the flight instruments briefly twice at the apex. It could not be positively determined if the altimeter was scanned during this time. The primary information required for the decision to continue or abandon the manoeuvre was the aircraft height. The study considered that the single-pointer needle of the altimeter, indicating hundreds of feet, was easily read, but that with the single-pointer between 700 and 800 ft, the thousand feet height counter number could be partially obscured as shown in Figure 28. The study identified three possibilities for his decision to continue the manoeuvre:

1. The pilot did not read the altimeter
2. The pilot misread the altimeter
3. The pilot used an incorrect gate height

Workload, distraction and expectation could all influence the accuracy of reading the altimeter but, with only four seconds available for deciding whether to continue or abandon the manoeuvre, the decision must be predetermined and instinctive. The height of 2,700 ft achieved at the apex of the accident manoeuvre was the gate height the pilot used for a 'bent loop' in the Jet Provost, and a decision to continue having achieved it would have been correct for the Jet Provost but not for the Hunter. Alternatively, if the pilot's attention was initially drawn to the ASI, seeing an airspeed of 105 KIAS, well below his expectation, may have distracted him from reading the altimeter or from reading it correctly.

The RAFCAM summarised its findings as follows:

> *'Analysis has been undertaken to identify the scope of human actions and/or decisions to have contributed to the loop being continued when below the pilot's stated minimum height at the apex. It is not possible to determine which, if any, of these actions took place based on the evidence available for the HF analysis, but the following accounts are considered credible and feasible:*
>
> a. *The altimeter may not have been seen or read at the apex of the loop as a result of scan pattern, high workload, allocation of attention, distraction (for instance, from detecting a reduction in thrust during the climb or the airspeed being lower than expected), and/or visual limitations (such as contrast and glare).*
>
> b. *An inaccurate perception of aircraft height may have been obtained, specifically, that the aircraft was higher than it was as a result of the altimeter displaying the incorrect altitude*[61]*, a misleading or ambiguous display of the altimeter digit drum* [height counter]*, the altimeter digit drum* [height counter] *being partially obscured, and/or the altimeter being misread.*
>
> c. *The minimum height required at apex may have been recalled incorrectly.*
>
> d. *An escape manoeuvre may have not been selected as a result of the limited time available to select and implement the action, and the guidance and training that the pilot received with regard to performing an escape manoeuvre at the apex of a loop in the Hunter.'*

The RAFCAM report is included at Appendix M.

61 The RAFCAM report was prepared before the results of the altimeter testing were available.

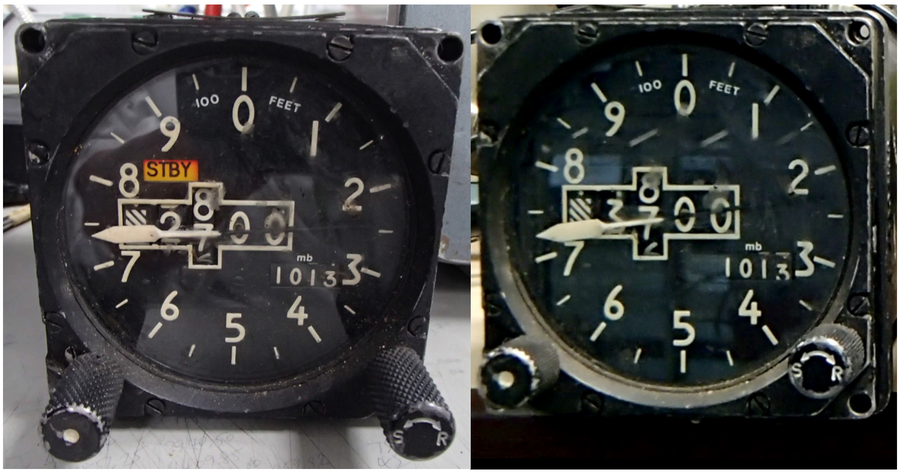

Figure 28

Altimeter height counter partially obscured by pointer
(Barometric pressure setting not as found)

1.18.10.3 Previous Safety Recommendation regarding human factors

AAIB Aircraft Accident Report 6/2009 made the following Safety Recommendation:

> **Safety Recommendation 2009-054**
>
> It is recommended that the UK Civil Aviation Authority introduce a recurrent programme of Human Factors training for display pilots. The training should specifically address human performance and its limitations when undertaking display flying and should form part of the Display Authorisation process.

The CAA responded in FACTOR F10/2009, revised on 9 April 2010, as follows:

> *'The CAA accepts this Recommendation. CAA Document 743 "Civil Air Displays, A Guide For Pilots", which is available on the CAA website, contains Human Factors advice in "plain English". The application procedure for a Display Authorisation requires a Display Evaluator to cover Human Factors in the form of personal limitations and the applicant's mental attitude to display flying. Further recurrent training for Human Factors was discussed at the 2009 Display Authorisation Evaluator's Seminar held in November 2009. An amendment has been made to CAP 403 "Flying Displays and Special Events: A Guide to Safety and Administrative Arrangements" to include a Human Factors reference in the Application Forms.'*

CAP 743 was superseded by CAP 1047, the current edition of which was published in July 2013.

1.18.11 CAA Review of Civil Air Displays

On 9 September 2015, in response to the accident to G-BXFI, the CAA announced that it would conduct a review of UK civil air displays with the intent of evaluating existing guidance, processes and regulations relating to civil flying displays.

On 28 October 2015 the CAA published CAP 1351, '*CAA Review of Civil Air Displays: progress report*' identifying the following themes which would form the main focus of the review: the overall regulatory framework, flying display locations, flying display aircraft and flying display people.

On 26 January 2016 the CAA published CAP 1371, '*UK Civil Air Display Review: Actions that impact on UK civil air displays in 2016.*' CAP 1371 identified 16 actions that the CAA planned to implement to increase the safety of the public, by introducing additional requirements and formalising existing requirements regarding the planning of flying displays and the roles, responsibilities and competencies of those involved in flying displays.

On 14 April 2016 the CAA published CAP 1400, '*UK civil air display review: final report*', identifying 29 actions (including those previously published in CAP 1371) which the CAA intend to implement as follows:

Action 1: The CAA will specify, for all future air displays, the risk assessment criteria that it requires event organisers and Flying Display Directors must use in planning and preparing for air displays of all sizes.

Action 2: In their application for permission to hold an air display, an event organiser and/or FDD must provide their enhanced risk assessment and full details of how they propose to mitigate any risks they have identified. They must set out in their safety plans evidence of engagement with other authorities.

Action 3: An event organiser must provide the CAA with written detail of how they, with input from the FDD, will communicate with the public about areas where they may be at greater risk.

Action 4: The CAA will formalise its procedures for ensuring whether, in its opinion, an applicant has the right attitudes and behaviours to fulfil the role of an FDD. The CAA will develop similar procedures for display pilots and Display Authorisation Evaluators (DAE).

Action 5: The CAA will accredit FDDs to meet a defined level of competence.

Action 6: At least one day before an air show, any pilot intending to fly aerobatic sequences that flow directly from one manoeuvre into the next must notify the FDD of the series of linked manoeuvres that they intend to perform. If the information is not provided, the FDD must not allow the pilot to fly in the air show.

Action 7: With effect from 1 April 2016, a display authorisation will only remain valid for pilots of all registered aircraft who hold either an EU medical certificate issued by an AME or an ICAO medical certificate that is of an equivalent or higher standard.

Action 8: The minimum relevant hours required for a pilot to obtain a DA for complex or high-performance aircraft will be increased.

Action 9: The CAA will strengthen the display pilot's initial validation process by introducing an additional revalidation after the first six months and require that no display pilot has the same DAE conducting the revalidation for more than two consecutive years.

Action 10: Currency

- display pilots authorised to perform at standard level aerobatics in multiple categories including jet powered and helicopter categories must renew in those categories at least every two years; and
- where that authorisation also includes one or more of turboprop, multi-engine piston (MEP) or single-engine piston (SEP) categories they must rotate their renewal across those categories year on year.

Action 11: A display pilot authorised to perform above standard level aerobatics and in more than one aircraft category will be required to renew their display authorisation in each category.

Action 12: The CAA will strengthen the criteria for the nomination, appointment, induction and documentation for DAEs. These criteria will be in effect for all appointments from 31 March 2016 onwards, including reappointments.

Action 13: The CAA will enhance the frequency and intensity of its oversight of DAEs to ensure that they are fulfilling their responsibilities to a satisfactory standard.

Action 14: The CAA will assist DAEs to maintain their own competency and continuing professional development by organising an annual DAE seminar.

Action 15: To obtain a display authorisation, pilots must be able to prove that they can plan and perform a series of linked manoeuvres.

Action 16: With immediate effect, no member of CAA staff will be permitted to act or sit on a Flying Control Committee, or to act as a DAE. CAA Flying Standard Officers will oversee flying displays and the DAE system.

Action 17: Pilots authorised to perform standard level aerobatics will only be permitted to perform loops or barrel rolls in civil registered ex-military jet aircraft at civil air displays if they have received explicit approval from a suitably qualified DAE. Approval will be made clear on a pilot's DA.

Action 18: FDDs must verify the DA of pilots wishing to perform standard level loops and barrel rolls in civil registered ex-military jet aircraft to confirm that they have the authorisation to perform the manoeuvres.

Action 19: With immediate effect

- where a display aircraft is performing aerobatics at a speed of between 200 and 300 kt IAS, the minimum distance between the crowd and the display line must be 230 metres;
- where a display aircraft is performing at a speed in excess of 300 kt IAS, and the display includes any high speed manoeuvres towards the crowd, the minimum distance between the crowd and the display line must be 450 metres; and
- for light aircraft, with a maximum weight of less than 1200 kg and operating speeds of less than 150 kt IAS throughout the display, the minimum separation is 150 metres.

Action 20: From publication of this report, and until further notice, operators of civil registered ex-military jet aircraft must seek formal approval from the CAA to perform aerobatic manoeuvres below 500 feet.

Action 21: With immediate effect the weather minima for flying displays by aircraft other than V/STOL aircraft operating in jet-borne flight/V/STOL mode, rotorcraft and other aircraft with a stalling speed below 50 knots, flying flat aerobatic displays, will be 500 ft cloud base BKN[62] and OVC[63] and 5 km visibility for both solo and formation displays.

Action 22: From the 2016 display season onwards all event organisers and FDDs must submit a post-air display report to the CAA. Pilots must also report any aspect of their display that could have caused a significant safety risk.

62 Indicates "broken" cloud, by which more than half the sky is covered.
63 Indicates "overcast", by which the sky is obscured.

Action 23: FDDs will be responsible for reporting all breaches of safety at their display to the CAA. Where a 'stop' call is made during a display for reasons related to the fitness or competence of a pilot the circumstances leading to the 'stop' must be reported to the pilot concerned and to the CAA as soon as practicable. In such circumstances the CAA will issue a provisional suspension of the display authorisation to the pilot concerned.

Action 24: We will review the criteria and requirements for the acceptance of ex-military aircraft onto the civil register. This work will be completed by early 2017.

Action 25: We will require maintenance schedules for ex-military aircraft on the civil register to be provided to the CAA, so that we can harmonise schedules and improve the standard of these documents. This work will be completed by the end of 2016.

Action 26: We will work closely with the MAA[64] and the Ministry of Defence to enhance the CAA's understanding of the revision levels of key military publications on which maintenance schedules for which ex-military aircraft are based. This work will be completed by the end of 2016.

Action 27: We will conduct a review of all ex-military aircraft on the civil register that are required to have ejection seats fitted and active to ensure that they are necessary and appropriately maintained. This work should all be concluded by early 2017.

Action 28: We will establish continued airworthiness boards for different types and classes of aircraft to facilitate regular exchange of airworthiness information of type- or class-specific best practice. We expect the first of these meetings to be held before the end of May this year.

Action 29: The CAA will commence a programme of work to study and enhance understanding of human factor issues within the air display sector, starting with a full-day industry workshop on the causes and impact of human error for display pilots (date to be set).

The CAA review of UK civil air displays was separate from the AAIB's investigation into the accident to G-BXFI. However, the AAIB kept the CAA informed of safety issues emerging from the investigation in order to facilitate safety improvement and enable the CAA to take action where necessary. CAP 1371 and CAP 1400 identify proposed CAA actions in some of the same areas addressed by AAIB Safety Recommendations arising from this investigation.

64 Military Aviation Authority.

1.18.12 CAA organisation for general aviation

The CAA General Aviation Unit was set up in 2014 and emerged from the Government's 2013 General Aviation Red Tape Challenge, which explored ways to reduce the regulatory burden on the general aviation (GA) sector. The CAA document, CAP 1283, GA Annual Report 2015, states:

> *'The GA Unit is involved in most of our GA activity and is accountable for the regulatory oversight of: airworthiness, operations and associated personnel training and licensing for non-commercial[65] operation of other than complex[66] aircraft. This encompasses aircraft ranging from microlights, historic and amateur-built aircraft, through balloons, gliders, piston twins and single-engine turbine aeroplanes up to 5700kg maximum weight and single-pilot helicopters up to 3175Kg. The Unit also has oversight of GA-aligned non-EASA aerodromes.'*

CAP 632 categorises Permit-to-Fly ex-military aircraft, overseen by the GAU, as follows:

> *'a) Simple: single piston engine types.*
>
> *b) Intermediate: multiple piston engine or turbine (single or multiple) engine types with simple mechanical flying controls or with power controls having an independent back-up system which ensures continued safe flight.*
>
> *c) Complex: all other types, in particular those types having features which require a high degree of specialised knowledge and equipment to maintain (e.g. types with no independent back-up system to powered flying controls or with auto-stabilisation systems or electronic engine controls).'*

Note that classifications in CAP 632 are different from those used by EASA. The CAA GAU oversees Hunter aircraft, which it categorises an intermediate type, whereas it meets the EASA definition of a complex type and, with an MPAUM of 25,000 lb (11,340 kg) is heavier than the maximum 5,700 kg that the GAU's statement indicates falls within its remit.

65 The EASA defines 'commercial operation' as any operation of an aircraft, in return for remuneration or other valuable consideration, which is available to the public or, when not made available to the public, which is performed under a contract between an operator and a customer, where the latter has no control over the operator. The ANO states that flights that are wholly or principally for the purpose of taking part in a flying display are considered non-commercial.

66 The EASA definition of 'complex' includes aircraft with a maximum takeoff mass of over 5700 kg and/or fitted with a turbojet engine. CAP 632 defines 'simple', 'intermediate' and 'complex' categories of aircraft. The CAA has categorised the Hunter as an intermediate type.

Staff from all levels of the GAU reported that they thought the GAU had been resourced at an appropriate level for its day to day core activities but that the pace of the change programme it was undertaking at the time had been a challenge to the unit's capability. Activities arising as a result of the accident to G-BXFI had added to the unit's workload.

The CAA set out its goals for general aviation in its document, *General Aviation Success Measures.* These goals included:

> *'Ensure the processes, legal basis, policies and guidance are in place to enable maximum delegation of CAA responsibilities to organisations.*
>
> *Address GA Red Tape Challenge recommendations via the GA Programme as agreed with the General Business and Aviation Strategy Forum (GBASF).*
>
> *Reduce airworthiness oversight by at least 20% by 2018 through delegation to other organisations and through implementation of Performance Based Regulation.*
>
> *Produce a rational and proportionate fees & charges model.*
>
> *Complete Impact Assessments for all policy/legal changes and conduct an accurate assessment of the cost/benefit analysis.*
>
> *Ensure all regulatory/de-regulatory/ delegation changes are made using a 'balance of risk' approach.*
>
> *No reduction in 3rd party safety as a result of reduced regulation.*
>
> *Improve the reputation of the CAA externally as a result of the CAA embedding the Red Tape Challenge principles.*
>
> *Continue to work in partnership with the GA Community.'*

Prior to the formation of the GAU, the CAA conducted an exercise to produce a risk or complexity triangle. This ranked the relative airworthiness risk or complexity of aviation organisations as a means to determine the oversight required. Typically the higher risk/more complex organisations would be subject to more oversight. This resulted in most general aviation organisations being ranked as 'green – low risk' and therefore subject to the lowest levels of oversight. This 'low risk' category included ex-military jet aircraft. Towards the end of 2012 the CAA decided not to allocate a specific surveyor to a number of approved organisations, including the maintenance organisation responsible for G-BXFI. The CAA allocated a specific surveyor to the maintenance organisation in November 2014.

The GAU informed the AAIB that it intends to refine the oversight arrangements for general aviation organisations as it moves towards performance based oversight and it feels this will add a degree of fidelity to the risk picture and therefore lead to more appropriate levels of oversight for the various organisations within the GAU remit. So far it has applied this methodology to Approved Training Organisations and Ballooning. However, the planned roll-out has been delayed to allow GAU resources to be diverted to the CAA's response to this accident.

1.18.13 Original Equipment Manufacturer (OEM) support, documentation and training

1.18.13.1 OEM support

When jet aircraft like the Hawker Hunter were in military service they were maintained by organisations with significant facilities and trained personnel. In this environment maintenance personnel underwent a structured training regime which provided them with the appropriate skills and understanding to maintain a wide variety of military aircraft. Additional type-specific training was provided by the military organisation and/or the OEM. The OEM also provided maintenance planning documentation, technical manuals, a publication amendment service and specialist technical support. The OEM's also ensured that the experience of the worldwide fleet of a particular type was shared with all the relevant organisations. When the aircraft type retired from military service the support provided by the OEMs ceased.

As a result, the AAIB made the following Safety Recommendation in AAIB Special Bulletin S4/2015 published on 21 December 2015:

Safety Recommendation 2015-43

It is recommended that the Civil Aviation Authority establish a process for the effective dissemination of ex-military jet aircraft experience and type-specific knowledge to individual maintenance organisations.

The CAA responded to this Safety Recommendation in FACTOR F1/2016, published on 8 April 2016:

'The CAA accepts this recommendation. By December 2016, the CAA will establish and promote a process for the more effective dissemination of ex-military jet aircraft experience and type-specific knowledge between individual maintenance organisations.'

The AAIB categorised the CAA response as '*Adequate – Closed*.' The CAA has indicated that this process is now in place.

1.18.13.2 Documentation

Technical publications for this type of aircraft were written in the 1950's and 1960's and assumed that maintenance personnel had a level of competence commensurate with military operation. The manuals did not always include comprehensive instructions and were written in a style different from current manuals for civilian aircraft. These documents are no longer subject to routine amendment.

The planning document approved by the CAA for the maintenance of G-BXFI was the Master Servicing Schedule issued in 1977 and reprinted 1990. This document details the maintenance tasks to be carried out on the aircraft, component installation lives and defines the aircraft's maintenance cycle as follows:

Servicing	Cycle (flying hours)
Primary	60
Primary Star	120
Minor	240
Minor Star	480
Major	960
Major (2)	1,920

Table 13

Maintenance requirements

Due to the low utilisation of G-BXFI (compared to its use in military service) the current maintenance organisation carried out a 'Primary' check annually and a "Primary Star" inspection every two years.

A Hawker Hunter T7 Aircraft Servicing Manual provided to the AAIB by the RAF included 20 additional amendments which were not included in the equivalent manual that was used to maintain G-BXFI. The maintenance organisation stated that it had taken steps to determine if more up to date manuals were available by contacting other maintenance organisations and museums, but were unable to obtain a more recent manual.

It has not been possible to establish the changes introduced by individual amendments or their effect on the standard of aircraft maintenance. Discussion with the CAA confirmed that there is currently no established minimum amendment standard for the technical publications of ex-military jet aircraft.

As a result of this, the AAIB made the following Safety Recommendation in AAIB Special Bulletin S4/2015 published on 21 December 2015:

> **Safety Recommendation 2015-44**
>
> It is recommended that the Civil Aviation Authority establish a minimum amendment standard for the technical publications for each ex-military jet aircraft operated on the United Kingdom civil register.

The CAA responded to Safety Recommendation 2015-044 in FACTOR F1/2016, published on 8 April 2016

> *'The CAA does not accept this recommendation. Each ex-military aircraft accepted by the CAA is on the basis of its individual build and modification standards and as such, examples of the same type may be operated and maintained to different manual amendments perfectly justifiably – it may not be desirable or even possible to establish a minimum standard for each publication.*
>
> *However, the sharing of information at type or class forums and the review of maintenance programmes mentioned in the Air Display Review may result in some aircraft adopting a later standard of publication, where appropriate.'*

The AAIB categorised this response as '*Not adequate - Open*'.

CAA document CAP 1400, Section 7.12 (version 1.2, published in May 2016) stated:

> *'There is some variation in the amendment status of the military publications on which maintenance schedules for ex-military aircraft are based. As part of our work to improve the standard of these schedules, we will investigate this variation to ensure that it does not affect the airworthiness of the ex-military aircraft fleet.'*

In the same document, Action 26 stated:

> *'We will work closely with the MAA and the Ministry of Defence to enhance the CAA's understanding of the revision levels of key military publications on which maintenance schedules for ex-military aircraft are based. This work will be completed by the end of 2016.'*

The CAA amended its response on 28 July 2016, stating:

> *'The CAA will revise those AAN's that currently do not reference specific amendment states for each ex-military aircraft with a valid Permit to Fly to include this information before the end of December 2018.'*

FACTOR F1/2016 Issue 2, published by the CAA on 24 January 2017, stated:

> *'Working in conjunction with industry, the CAA will establish a minimum amendment standard for the technical publications for each individual ex-military jet aircraft operated on the UK civil register. The established standard will be recorded in the Airworthiness Approval Note (AAN) for each aircraft.*
>
> *The CAA will complete this work by December 2018.'*

The AAIB re-categorised the CAA response to Safety Recommendation 2015-44 as '*Adequate – Closed*'.

The CAA confirmed that maintenance organisations are responsible for the development of the aircraft maintenance programme for each individual ex-military jet aircraft under their control. These are usually based on the maintenance planning documentation used when the aircraft was in military service. The rights for the maintenance programme are held by the organisation which developed it. If the aircraft is transferred to another maintenance organisation the maintenance programme remains the property of the originating organisation, and therefore might not be passed on to the new maintenance organisation.

Accordingly, the AAIB made the following Safety Recommendation in Special Bulletin S4/2015 published on 21 December 2015:

> **Safety Recommendation 2015-45**
>
> It is recommended that the Civil Aviation Authority require that an ex-military jet aircraft's maintenance programme be transferred with the aircraft when it moves to another maintenance organisation to ensure continuity of the aircraft's maintenance.

The CAA responded in FACTOR F1/2016, published on 8 April 2016, as follows:

> *'The CAA does not accept this recommendation. The maintenance programme for an individual aircraft is customised to the particular operation of the aircraft at a given time so continuity may not always be appropriate. This is not unique to the ex-military aircraft community but is common across the aviation industry.*
>
> *The maintenance programme is the proprietary information of its author(s), though an organisation may opt to transfer it with an aircraft. The owner and maintenance organisation to which an aircraft is transferred are required to establish a maintenance*

> *programme that is suitable for the aircraft, with consideration to its operation and previous maintenance history, which is recorded in the logbooks and technical records that are transferred upon a change of ownership and/or maintenance organisation. The CAA considers that this facilitates an appropriate level of continuity of the aircraft's maintenance, where appropriate.'*

The AAIB categorised the CAA's response to Safety Recommendation 2015-45 as '*Not adequate – Open*'.

CAP 1400, Section 7.11, stated:

> *'We know there are differences in approach between individual operators and their Maintenance Organisations and Continuing Airworthiness Management Organisations (CAMO) when producing such schedules for ex-military aircraft. We are currently reviewing a wide range of schedules, with a view to harmonise them and so reducing risks. This may result in additional guidance being developed.'*

In the same document, Action 25 stated:

> *'We will require maintenance schedules for ex-military aircraft on the civil register to be provided to the CAA, so that we can harmonise schedules and improve the standard of these documents. This work will be completed by the end of 2016.'*

The CAA updated its response to Safety Recommendation 2015-045 in FACTOR F1/2016 Issue 2, as follows:

> *'The CAA is developing a proposal for consultation with industry to introduce a new requirement into BCAR Section A to require a maintenance programme to be transferred with an ex-military jet aircraft if it moves to a new maintenance/continuing airworthiness management organisation, or new owner/operator.*
>
> *Subject to the outcome of the process of industry consultation, the CAA intends to implement this requirement by April 2018.'*

The AAIB re-categorised the CAA's response to Safety Recommendation 2015-45 as *'Adequate – Closed'*

1.18.13.3 Training of maintenance personnel

The investigation found that civil organisations maintaining ex-military aircraft usually employ a number of maintenance personnel with prior military aircraft maintenance experience some of whom may be familiar with the relevant aircraft type and its manuals. The lack of OEM support, and the limited number of ex-military jet aircraft on the civil register, means that there are no training courses available for civil aircraft maintenance personnel to maintain former military jets. Type-specific training is usually undertaken in-house using ex-military personnel to pass on their experience and understanding of the aircraft.

1.18.14 Mandatory Permit Directive 2001-001

1.18.14.1 Background

Following the investigation of a fatal accident to a Hawker Hunter in 1998 the AAIB published Safety Recommendation 99-27 which stated:

> *'In view of the marked reduction in flying utilisation of ex- RAF Hawker Hunter jet aircraft which have been acquired for civilian use and the related greatly increased calendar time between scheduled overhaul of the fuel and air system components on their Avon turbojet engines it is recommended that the CAA, in conjunction with Rolls Royce, consider the introduction of appropriate calendar time overhaul periods for such engine systems, the serviceable condition of which can be calendar time dependent due to component material 'ageing' affects.'*

In response to this Safety Recommendation the CAA issued MPD 2001-001 on 18 May 2001 (see Appendix N), which stated:

> *'Reason: Following an investigation into a fatal accident to a Hawker Hunter on 5 June 1998,the Air Accidents Investigation Branch have recommended that consideration be given to imposing calendar life limits on fuel and air systems fitted on Avon engines, since these systems may be subject to ageing effects.*
>
> *It is recognised that ageing effects may not be confined solely to fuel and air systems. Corrosion of discs and blading, for example, may also be time dependent. The CAA has experience of accelerated corrosion occurring on engines fitted to aeroplanes of low usage, and the possibility of an age related failure to either the control units or core engine cannot be discounted.'*

The MPD imposed a maximum overhaul life of 15 years on the Rolls-Royce Avon 1, 100 and 200 series engines but, recognising that the integrity of the engine could be monitored by routine inspection and tests, the MPD also stated:

> *'Alternative Means of Compliance*
>
> *The intent of this MPD is to prevent potential calendar time related engine deterioration developing to a point where engine integrity is compromised.*
>
> *The CAA will consider alternative inspection/test and sampling programmes which can be shown to prevent unacceptable deterioration of engines in service. Operators may wish to propose such programmes in lieu of engine withdrawal from service. These programmes must, however, be underwritten by an approved BCAR A8-20 organisation or the manufacturer and must address all ageing related deterioration which could occur on the Avon engine series.'*

1.18.14.2 Assessment of AMOC applications

In order to assess applications for AMOC's to existing MPD's the CAA uses internal Airworthiness Division Technical Procedure, *'TP-CAW-18, Dealing with Applications of Alternative Methods of Compliance (AMOC) to an Existing Airworthiness Directive or Mandatory Permit directive (Non-EASA Products)'.* The process is summarised in a flow chart (see Figure 29).

The CAA informed the AAIB that a number of applications for AMOCs to MPD 2001-001 have been approved, which can vary from aircraft to aircraft based on a number of considerations, including utilisation. Many of these AMOC's have been in place for several years and are unaltered from their original approval.

1.18.14.3 Compliance with MPD 2001-001

Historic records showed that in October 2009, when G-BXFI had been operated by a previous operator, inspections of the compressor, turbine, combustion system, bleed valves and external hoses had been completed. The aircraft maintenance log had been annotated with '*Biannual MPD 2001-001 compliance carried out I.A.W. MOE Chap 19'.* The CAA had approved an AMOC to MPD 2001-001 as part of that operator's approved Maintenance Exposition.

Records from the subsequent maintenance organisation confirmed that a number of similar inspections had been completed in January 2011, but no reference to MPD 2001-001 was found.

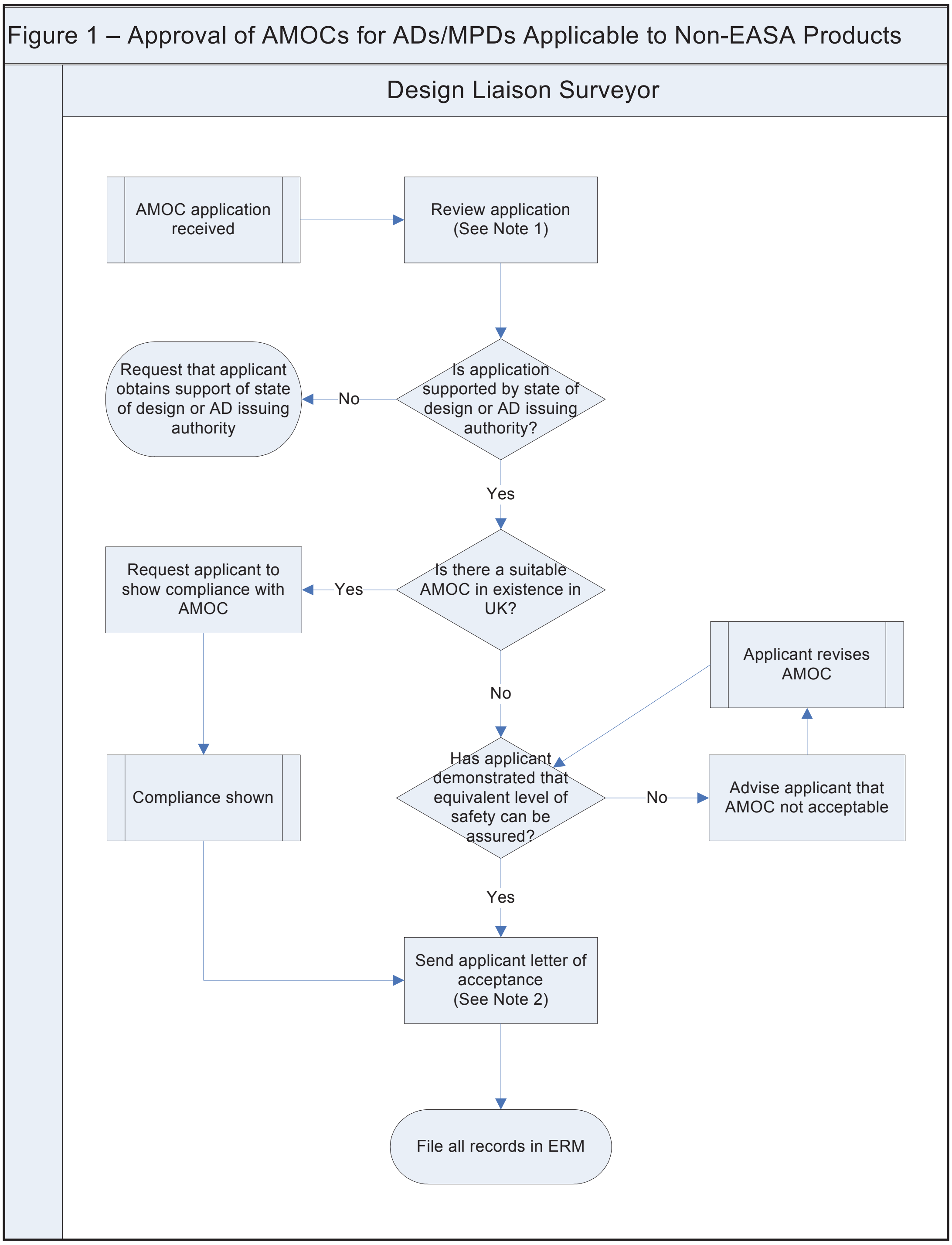

Figure 29

CAA process flow chart for dealing with AMOC applications to existing MPD's

Neither that maintenance organisation, nor the one responsible for maintenance of the aircraft at the time of the accident, had access to the original Exposition and were therefore unware of the full scope of the approved AMOC to MPD 2001-001. The current maintenance organisation stated that its inspection programme to satisfy the requirements of an AMOC to MPD 2001-001 was based on historic technical log entries which had been annotated with a reference to MPD 2001-001, without access to the original AMOC or the detail it contained.

The aircraft was transferred to the current maintenance organisation in July 2012. Its maintenance records showed that during a "Minor Star" maintenance check, carried out between August and December 2012, the current maintenance organisation removed the engine from the aircraft for a number of inspections. These matched those completed in 2009. In addition, the current maintenance organisation took an oil sample which was analysed using Spectrographic Oil Analysis Programme[67] (SOAP). The aircraft's records stated that these inspections had been completed to confirm the engine's compliance with MPD 2001-001. The maintenance organisation stated that these inspections were based on previous inspections recorded in the aircraft's historic maintenance records.

The ACAM audit of the aircraft conducted by the CAA on 3 January 2013 (see Section 1.6.14.1) did not make specific reference to an AMOC for MPD 2001-001.

A 'Primary' inspection was conducted on G-BXFI between January and March 2014 during which the engine was removed, and the engine inspections carried out on the 'Minor Star' maintenance check of 2012 were repeated. The aircraft records were annotated to indicate compliance with MPD 2001-001.

The AAIB investigation did not identify a specific approval for an AMOC to MPD 2001-001 for this aircraft, either in the current maintenance organisation's approved Exposition, correspondence between the CAA and the current maintenance organisation or in the aircraft's historic maintenance records. During discussions between the AAIB and the CAA in September 2015, the CAA confirmed that the current maintenance organisation did not hold a CAA-approved AMOC to MPD 2001-001.

67 SOAP- Spectrographic Oil Analysis Program, a method of analysing oil and other fluids for the presence of microscopic particles suspended in the fluid. It is used to identify wear in oil wetted components such as bearings and requires numerous routine samples to define a "baseline" from which deterioration trends can be identified.

Section 8 of CAP 562 Leaflet 70-80 – *'Guidance Material for Ageing Engine Continuing Airworthiness'* (see Appendix O), states:

> *'Gas Turbine Engine- Generic or Possible AMOC Elements'*
>
> *8.1 Particularly relevant for gas turbine engine, where possible the following data could be considered for collection at each engine run, as permitted by the type:*
>
> *a) Pilot reports*
> *b) Oil consumption rates/trend monitoring*
> *c) Gas path performance trend monitoring*
> *d) (e.g.T.G.T spool speeds etc.):*
> *e) Engine run down times*
> *f) Vibration monitoring (if systems equipment is fitted)*
> *g) Engine running times (including ground runs)*
>
> *8.2 The above information should be formally recorded as relevant for each flight, and issues such as gas path parameters, vibration and oil consumption trending plotted for evidence of datum shifts. It is quite likely that optimum health monitoring could be carried out by flight crew at a steady state phase of engine operation.'*

Examination of the engine records relating to engine ground running indicated that although no performance figures had been recorded, the engine remained within limits. The only record of engine parameters in flight were those from two routine air tests. Both of these reports included rpm exceedences which were not reported to the maintenance organisation and therefore no remedial action was taken. The maintenance organisation stated that there was no programme in place to routinely record and monitor engine operational performance.

Communication between the maintenance organisation and the CAA

In mid-January 2014 the organisation responsible for maintenance of the aircraft at the time of the accident contacted the CAA with a proposal for an AMOC to MPD 2001-001, which included annual SOAP samples. The proposal included the following statement:

> *'... it is proposed to increase SOAP analysis to include fuel systems to test for seal polymer deterioration.'*

The CAA responded to the maintenance organisation at the end of January 2014 with additional information, contained in CAP 562 Leaflet 70-80, which should be considered by the maintenance organisation in any formal submission of an AMOC. The response also commented that the proposed

AMOC did not include any tasks to verify the condition of bleed valves, flexible hoses, fuel pumps and the FCU. During an interview with the AAIB the intended recipient of the email confirmed that he had no recollection of receipt of the email and no additional submission of a proposed AMOC to MPD 2001-001 was made to the CAA.

In April 2014, the maintenance organisation contacted a CAA surveyor to obtain an update on the progress of its AMOC for MPD 2001-001 which was passed to the General Aviation Department of the CAA. The investigation has not been able to identify any response from the CAA to the enquiry.

CAA action

On 19 December 2015, members of the CAA GAU reviewed records relating to G-BXFI and stated to the AAIB that it was unclear whether a legally valid AMOC to MPD 2001-001 was in place for G-BXFI at the time of the accident. The CAA later advised the AAIB that, in its opinion, the current maintenance organisation had completed tasks associated with a pre-existing AMOC to MPD 2001-001 and that therefore the aircraft was compliant with MPD 2001-001.

The AAIB requested documentary evidence to support the CAA's assessment. The CAA provided a summary document stating:

> *'The CAA holds records of the A8-20 Maintenance Organisation Exposition for* [a previous maintenance organisation]*, who were formerly approved by the CAA to maintain G-BXFI. This Exposition contained the AMOC approved by the CAA for work on G-BXFI in accordance with MPD2001-001.'….*
>
> *…'The CAA cross-referenced this work against a copy of the Exposition for* [a previous maintenance organisation]. *The engine check work was carried out by* [the current maintenance organisation] *in line with the tasks defined as part of the approved AMOC'.*

The CAA also provided the AAIB with a document called *'AMOC - G-BXFI'* which included a table of engine maintenance tasks and later provided a copy of a previous maintenance organisation's 'Exposition'. Part 2 of the Exposition, 'The Procedures Manual', included the following statement:

> *'This maintenance programme is the alternative means of compliance with MPD 2001-001 as agreed with the CAA for Avon engines operated and maintained by* [the previous maintenance organisation]. *Any deviation to this programme is to be submitted to the CAA for approval.'*

A copy of a letter from the CAA to a previous maintenance organisation, entitled *'CAA Approval of Organisations'* and dated 15 March 2011, was included.

This indicated CAA approval of the Exposition, which contained an AMOC to MPD 2001-001. The Exposition stated that it was only applicable to Avon engines operated and maintained by that maintenance organisation.

The records for G-BXFI indicate that it had been maintained by another organisation since January 2011 and was therefore not under the provision of this previous organisation at the time the Exposition was approved.

Section 3.1 of CAA document CAP562 – Book 1, leaflet C-30, *'CAA Approvals – Non Transferability'*, states:

> *'CAA Approval is granted to a legal entity and, in the case of an organisation, this is clearly identified with its company registration number. A CAA Approval once granted is not transferable from one registered company to another.'*

The CAA stated:

> *'The CAA did not issue a separate AMOC approval for MPD 2001-001 to* [the operator] *or* [the maintenance organisation]*.'*

The ANO 2009 states:

> *'Article 22 National permits to fly ceasing to be in force and issue of airworthiness directives for permit aircraft*
>
> *(1) A national permit to fly ceases to be in force if:*
>
> *(a) The CAA has issued a directive that requires:*
>
> *(i) an inspection to be carried out for the purposes of ascertaining whether the aircraft remains airworthy…*
>
> *(b) Completion of an inspection, modification or maintenance of the aircraft is required as a condition of the permit to fly…'*

1.18.14.4 Other relevant engine-related events

The AAIB report of its investigation into a fatal accident to Hawker Hunter F4, GHHUN, in June 1998, stated:

> *'… records kept on a computerised database between 1980 and 1992 showed 22 cases involving the Avon Mk 122 engine where engine speed had dropped and subsequent engineering investigation had not established a clear cause. Anecdotal evidence indicated that Avon Mk 122 engines had suffered from unexplained power reductions from time to time during RAF service, but in most cases the aircraft had returned safely and the subsequent RAF engineering investigations, including related engine ground runs, had failed to identify associated causes or to reproduce the symptoms.'*

A review of the investigation files did not identify the source of the computerised database.

In 2013 a Hawker Hunter T7 suffered from a complete loss of thrust as a result of the failure of a compressor blade. The cause of the failure was corrosion-initiated fatigue in the blade pin-hole attachment lug. A number of other cracks were found in other blades from the same stage. The CAA determined that the presence of corrosion in this area could not be identified by in-situ inspections typically included under an AMOC to MPD 2001-001. On 7 October 2016 the CAA published MPD 2016-002 (shown in Appendix P), which introduced a requirement to remove the first four stages of compressor blades from the engine for initial and repetitive inspection.

1.18.15 Ejection seats

1.18.15.1 Ejection seats in ex-military aircraft on the UK civil register

Ex-military aircraft are accepted onto the UK civil register on the basis of a satisfactory military safety record. Where the presence of aircrew escape systems, such as ejection seats, contributed to that safety record, the CAA expects that the aircraft will continue to operate with these systems in a serviceable condition. The CAA has approved the disarming of ejection seats in some straight-wing ex-military aircraft, where it considers the aircraft has a landing speed low enough to allow a pilot to make a forced landing. However, based on the higher operating speeds of swept-wing ex-military jet aircraft, the CAA requires these aircraft to operate with serviceable ejection seats to provide a means of aircrew escape.

Paragraphs 5.8 and 5.9 of CAP 632 make the following statements regarding swept-wing ex-military aircraft equipped with ejection seats:

> *'5.8 Where ejection seats are an integral part of the aircrew escape system, as specified in the relevant Pilots Notes, Flight or Aircrew Manuals, it is recommended that they be fully serviceable for all flights. Approval should be sought from the CAA (Application and Approvals) at the earliest opportunity if it is intended to operate with inert ejection seats (or other escape systems). It is unlikely that the CAA will allow swept-wing aircraft fitted with ejection seats to be flown unless the equipment is fully operational.*
>
> *5.9 Ejection seat cartridge lives are typically 2 years installed, within a 6 year shelf life. To be fully serviceable the cartridges installed must be within their appropriate lives.'*

Section 2 of the Hunter T7 Master Servicing Schedule, *'Component Replacement List (Mandatory Changes)'*, states that the ejection seat cartridges require replacement every two years due to *'explosive life'*.

In addition, G-BXFI's AAN states:

> *'Cartridges for the Aircrew Assisted Escape System have a 6 (six) year overall/shelf life and 2 (two) year installed life…..'*

Section 10 of the AAN states:

> *'This aircraft must be maintained by a company approved under BCAR A8-20 and rated for the aircraft type (and with consideration given to the ejection seats), in accordance with the AP manuals and schedules referred to in Section 6 above and as agreed with the CAA Regional Office. In the event that the agreed arrangements are to be changed, the maintenance proposals will need to be reviewed and approved by the appropriate CAA Regional Office. The aircraft is to be kept hangared and inhibiting/short term care and maintenance procedures observed to prevent the onset of corrosion in the engine.'*

Chapter 5 of the CAP 733 – *'Permit to Fly Aircraft'* describes maintenance of ex-military aircraft. Paragraph 5.4 of that chapter states:

> *'5.4 Ex-military aircraft may have specific life limits for the aircraft structure or critical components defined by the manufacturer, these limits must not be exceeded. Where the manufacturer permits*

Factual Information

> *further operation for a period dependent upon the embodiment of additional modifications by more comprehensive and in-depth maintenance checks, these must be carried out before an extension to the operating life will be agreed. There will be no extension of aircraft life limits beyond those that are defined and supported by the manufacturer.'*

This indicates that the cartridge life specified in AAN No. 26172 was a requirement and not guidance or a recommendation.

In respect of ejection seats, CAA document TP-DAW 23-2, paragraph 11.3.1, describes the limitations on aircraft with live ejection seats as follows:

> *'For aircraft operated with live seats, the appropriate type of seat must be fitted and it must be maintained in accordance with appropriate publications. These are to be referred by type, manufacturer, serial number and publication on the AAN approving the aircraft.*
>
> *Cartridges powering such seats will be life limited and the lives should be quoted in the AAN. Manufacturers' lives are employed rather than those arbitrarily extended by former Eastern Bloc military authorities.'*

Additionally TP-DAW-23-2 refers to internal Airworthiness Guidance document GU-DAW-49 '*Aircraft ejection seat maintenance – service information*' dated 23 September 2010, which states:

> *'Ejection seat structure and the majority of components are replaced "On condition" as determined by a qualified tradesman during maintenance procedures following a*[n] *approved schedule, but there are many components subject to both strict shelf life, total life, and installed life limitations. In addition to these normally encountered life limit parameters, it is a requirement to control cartridge and rocket motor life from the date of unit filling.'*

1.18.15.2 Information from the ejection seat manufacturer

Cartridge lives

Martin-Baker Aircraft Company Ltd. recommends that for climates where the shade temperature is not likely to exceed 30ºC, the installed life of the ejection seat and canopy jettison cartridges does not exceed 2 years and that the total life does not exceed 6 years, from the date of cartridge manufacture[68].

68 Martin-Baker Aircraft Company Ltd: Service Information Letter (SIL) 90: *'Aircraft assisted escape systems – Recommended lives of components for Mk 2 to Mk15 ejection seats'* dated September 2014.

Cartridge life limits are introduced because the volatile components of the propellant gradually evaporate or 'cook-off' with age. This process may be accelerated by the environmental conditions to which the cartridges are exposed. The installed life is limited to two years because aircraft vibration disturbs the grains of the propellant, gradually reducing their size and changing the cartridge firing characteristics.

The ejection seat manufacturer advised the AAIB that using time-expired cartridges could increase the risk of an un-commanded ejection; or, when ejection is commanded, could result in increased discharge time of cartridges affecting the ejection sequence, or uncontrolled explosion of the cartridges.

Historic ejection seats

Martin-Baker ejection seats are designed and built exclusively for use in military aircraft. The Mk 4HA seats, fitted to G-BXFI, were derived from the Mk 4 seat designed in the late 1950s, and modified in the early 1960s specifically for the Hawker Hunter. Production of the Mk 4HA seats ceased in the early 1970s. Like many other models of ejection seat, the Mk 4HA is no longer operated by the military and the associated drawings and manuals are now obsolete. However seats of this type, and similar types, are installed in ex-military aircraft operating on civil aircraft registers, both in the UK and overseas.

Historically, Martin-Baker has not supplied ejection seats or components spares directly to civilian operators of ex-military aircraft. However, until 2015 Maker-Baker provided component spares to an intermediate supplier, which maintained ejection seats and provided component spares to the civilian ex-military market, both in the UK and overseas.

In February 2015 Martin-Baker took the decision to stop providing technical support and replacement parts for 'historic products'. It defines historic products as those ejection seats fitted to aircraft which no longer operate in their original military role. This includes secondhand products which have been sold by the original operator to a third party, even if that third party is a military user. This decision was based on the fact that these ejection seats are very old and were designed at a time when there was a very different risk tolerance to safety issues and hazards; the seat design and instruction manuals would not be deemed adequate by today's standards and many of the drawings and manuals for legacy products had become obsolete and Martin-Baker no longer had retained technical capability on these products.

Ejection seats installed in civil-operated ex-military aircraft fall into the historic product category and as such replacement spares, including cartridges, manufactured by the original manufacturer, are no longer available. Martin-Baker considers that such ejection seats should be deactivated to prevent the risk of inadvertent operation. This is contrary to the current CAA requirement for ejection seats in swept-wing aircraft to be operated in a fully operational and armed condition.

Martin-Baker met with the intermediate supplier in February 2015 to inform it of its decision to stop technical support and spares provision for historic products. Martin-Baker also took steps to identify civilian operators of ex-military aircraft equipped with historic ejection seats but did not directly inform any operators or the CAA of its position.

Martin-Baker communication with CAA

In November 2013 Martin-Baker contacted the CAA to discuss the use of ejection seats in civilian-operated ex-military aircraft and made reference to the following concerns:

- The age of the seats, many being beyond their design life and the standard of design which may not be acceptable for civilian purposes today.
- The standard of the instruction manuals given the age of the seat – the manuals relied on a higher standard of technical product knowledge and skill than could be expected today and may not meet the required standards today.
- The ability and willingness of civilian operators to operate and maintain seats in accordance with Martin-Baker instructions.
- The ability and willingness of civilian operators to comply with the total and installed life limit requirements of the pyrotechnic cartridges. Martin-Baker cited evidence based on lack of sales of pyrotechnics to civilian operators to support its assertion that cartridge lives must have been grossly exceeded in some cases.
- The potential for a catastrophic accident should a seat be inadvertently ejected causing an aircraft to crash into spectators at events such as flying displays.

Martin-Baker outlined its intention to advise against the use of live ejection seats in civilian aircraft but indicated that it wished to understand the CAA position on this subject, and any potential impact on the operation of these aircraft, before further action.

In response the CAA informed Martin-Baker of its policy on the use of ejection seats in ex-military aircraft, indicating that where fitted, ejection seats were expected to remain live unless specifically approved by the CAA. The CAA indicated that for Permit to Fly ex-military aircraft no involvement (Type Support) was expected from the original manufacturer, including the manufacturers of installed equipment.

Specifically in response to the concerns raised by Martin-Baker, the CAA indicated that it believed these areas were already addressed adequately by existing guidance. In particular it expected:

- Appropriate seat training to be imposed and controlled under the CAP 632 approval of the operator.
- Air displays to be controlled with the intent of reducing the likelihood of aircraft crashing into the crowd.
- Maintainers/operators to follow maintenance manuals and schedules and for this to be reviewed for annual revalidation of the Permit to Fly.
- The periodic overhaul of ageing ejection seats and the issue of cartridge lives to be appropriately observed by the approved organisation responsible for the aircraft's maintenance.
- Cartridge lives (total and installed) to be observed.

The CAA response made reference to the fact that when it had previously been approached for alleviation on ejection seat cartridge lives, such alleviation had been granted on the basis of evidence that new cartridges had been ordered and was only valid for a short duration (months). Specifically in respect to using out-of-life cartridges, the CAA stated:

> *'….we would view such a breach as serious and I'd suggest it would jeopardise the individual's approval.'*

The CAA further indicated that if it were to adopt a policy such as that proposed by Martin-Baker, whilst keeping the existing criteria for the deactivation of certain ejection seats, this would effectively ground the great majority of the UK ex-military jet fleet and would have serious consequences for the display community.

There was no further communication between the CAA and Martin-Baker on this subject prior to Martin-Baker's change of policy in February 2015.

1.18.15.3 Ejection seat maintenance

General

The service and maintenance of ejection seats is a specialist task. Civilian organisations operating or maintaining ex-military jet aircraft in the UK often rely on individuals or organisations with specialist skills and prior military experience in ejection seat maintenance to accomplish these tasks. The CAA does not issue specific maintenance approvals for specialised tasks such as ejection seat maintenance, and these tasks are instead performed under the maintenance approval of designated maintenance organisations, or delegated to specialist individuals or organisations. Some other regulatory authorities do issue maintenance approvals for specialist maintenance tasks, such as ejection seat maintenance. One example is the Civil Aviation Authority of New Zealand, which describes such an approval in Advisory Circular AC43-21 '*Escape and egress systems*', dated 25 December 1997.

Maintenance of G-BXFI's ejection seats

The maintenance organisation employed a technician who had previous ejection seat maintenance experience as an RAF Armourer. This individual performed maintenance on all the ejection seats under the responsibility of the maintenance organisation, but also carried out ejection seat maintenance for other organisations independent of his role at the maintenance organisation.

The maintenance organisation did not have specific facilities for ejection seat maintenance, however the ejection seat specialist had set up an ejection seat bay-servicing facility at his home. This facility was not under the control of the maintenance organisation, nor its BCAR A8-20 approval. The maintenance organisation was responsible for the provision of spares for the ejection seats.

The ejection seat and canopy jettison cartridges fitted to G-BXFI were from two separate production batches, manufactured in June and July 2008 and the manufacturing date was printed on the external casing of each cartridge.

Technical records provided with the aircraft indicated that the ejection seat and canopy cartridges had first been fitted to G-BXFI in December 2008 by a previous maintenance organisation and had been due to be replaced in December 2010, two years after being installed. However, an extension of their installation to January 2011 and then again to January 2012 had been recorded. Responsibility for the maintenance of the aircraft transferred to another organisation between March 2011 and June 2012. However no records relating to the ejection seat maintenance during that time were included with the paperwork subsequently provided to the current maintenance organisation.

The current maintenance organisation assumed responsibility for G-BXFI's maintenance in August 2012, and performed a substantial amount of maintenance on the aircraft between then and January 2013, including 'bay-servicing' of the ejection seats, which is required to be completed annually. The ejection seat cartridges were removed to facilitate this work and the same cartridges were re-fitted in November 2012[69]. The technical records were updated to indicate the cartridge life expiry dates as June and July 2014.

In January 2014, the maintenance organisation placed an order for new ejection seat cartridges and was advised by the supplier that they would be delivered in approximately 52 weeks. During the aircraft's annual maintenance inspection in February 2014, when the ejection seats were again bay-serviced, the maintenance organisation decided to leave the cartridges installed until the next scheduled annual inspection and updated the technical records to indicate that the cartridge installation had been extended until February 2015.

During the subsequent annual inspection in February 2015, the maintenance organisation again decided to leave the cartridges installed, as the new cartridges had not yet been delivered. The technical records were updated indicating that cartridge replacement was due in February 2016. The new cartridges were delivered in June 2015, but were not fitted to the aircraft.

The ejection seat maintenance and the associated removal and reinstallation of the cartridges was carried out by the maintenance organisation's ejection seat specialist but the relevant work cards and component log cards were signed off by the Deputy Chief Engineer.

Maintenance organisation cartridge life policy

The maintenance organisation informed the AAIB that it operated a 'six-year installed life' policy for ejection seat cartridges, rather than the two-year installed life specified by the manufacturer. However, this policy was not documented either in the company's Maintenance Exposition or in any other document. Approval for such a policy had not been sought from the CAA. However, the Chief Engineer believed that the policy had been discussed informally with a CAA Airworthiness Surveyor. The maintenance organisation subsequently documented its rationale for extending the cartridge lives in December 2015 and provided a copy of this to the AAIB.

The basis of the maintenance organisation's policy was that it considered the published manufacturer's cartridge lives to be recommended rather than ultimate lives, and based on the expected utilisation in their original military

69 AAIB Special Bulletin S4/2015 reported that the cartridges were fitted to G-BXFI in November 2012. Subsequent review of historic aircraft records indicated that the cartridges had first been installed in G-BXFI in December 2008.

roles. It considered that the utilisation of ex-military aircraft operating on a Permit to Fly was substantially less than the typical military utilisation, and therefore the cartridges would be subject to substantially less vibration and temperature-change effects than would have been the case in military service. Additionally it reasoned that as the aircraft were hangared when not in use, installed cartridges were subject to similar environmental conditions as stored cartridges, which were kept in the same hangar. It also asserted that the cartridges were subject to an annual visual inspection for any signs of degradation to the external casing or signs of deterioration of the fillings, such as discolouration or sweating. Furthermore the maintenance organisation were aware that one overseas military operator had operated a 10 ½ year total life and 3 ½ year installed life, for the same type of cartridges.

The organisation's approved Maintenance Exposition contained the following statement with regard to concession control:

> *'Requests for variations against scheduled maintenance requirements shall be raised on Form MA7 when it is not possible to complete the requirement, together with the reason for delaying the requirements. The Chief Engineer will approve the variation if he is satisfied that airworthiness will not be affected. If it is outside his power to approve the variation then he will refer the matter, in writing to the local CAA supervising Surveyor for consideration. Any variation agreed will be entered in the serialised variation file held in Technical Records, and in the aircraft's log books.*
>
> *Variations to scheduled maintenance check periods and component lives may be granted within the limits laid down by the schedule, subject to mandatory requirements or ultimate lives not being exceeded in the extension period.'*

The maintenance organisation stated to the AAIB that it considered the decision to extend the cartridge lives on G-BXFI was taken within the privileges of its A8-20 maintenance approval, and therefore it did not deem it necessary to seek formal approval from the CAA to extend the cartridge lives. Whilst the fact that cartridge lives had been extended was recorded on the Component Life Register for G-BXFI, there was no record of an internal approval, or technical justification for the cartridge life extension, either on 'Form MA7' or otherwise. Similarly there was no record of a variation in the variation file.

CAA position on G-BXFI ejection seat cartridge lives

During the investigation the CAA stated to the AAIB that it did not have a documented procedure for approving an extension to ejection seat cartridge lives, but it would consider any such applications on a case-by-case basis. It also stated that an extension would require prior written approval by the CAA, based on a technical justification submitted by the applicant and proof that new cartridges had been ordered. The CAA confirmed that there was no CAA approval or technical justification in place for the cartridge life extension on the ejection seats fitted to G-BXFI.

In December 2015 AAIB Special Bulletin S4/2015 highlighted the AAIB's initial findings regarding the ejection seat cartridges. As a result the CAA met with the maintenance organisation to discuss the basis on which the cartridge lives had been extended. Following that discussion the CAA changed its position and informed the AAIB, retrospectively, that it was satisfied that the decision by the maintenance organisation to extend the installed cartridge lives had been based upon reasonable technical assumptions, even though these had not been documented in advance, and that it considered this decision fell within the privileges of the organisation's maintenance approval. The CAA based this assertion on the fact that the organisation's Maintenance Exposition was a CAA-approved document, and the Exposition contained the statement relating to concession control. The CAA did not offer any position on the fact that the total cartridge lives had also been exceeded.

Other maintenance organisations

In the course of the investigation it has become apparent that the issue of time-expired ejection seat cartridges, used in civil-operated ex-military aircraft, is not confined to one aircraft or maintenance organisation.

1.18.15.4 Safety of first responders

Following the accident to G-BXFI, and a separate accident to a Folland Gnat[70] during a flying display at Oulton Park on 1 August 2015, the ejection seats fitted to both aircraft were found in a damaged condition. Some of the pyrotechnic cartridges were still live but had been subject to impact forces and post-crash fire. This posed a significant hazard to the first responders and to other personnel on the accident site. Accident response and investigation work in the vicinity of the seats was delayed until competent persons were brought to the site by the AAIB to make the seats safe. In both cases, the respective flying display organisers did not have access to relevant aircraft hazard information or emergency contact details for organisations which could render the seats safe. Ex-military aircraft may be equipped with other devices, such as miniature detonation cords or other pyrotechnic charges, which can also represent a hazard to first responders and accident site personnel.

70 Accident to Folland Gnat G-TIMM, reported in AAIB Bulletin 5/2016.

1.18.16 Safety actions taken

AAIB Special Bulletin S4/2015 contained seven Safety Recommendations in the areas of safety of first responders, ejection seats and aircraft maintenance, to which the CAA responded in FACTOR F1/2016. Special bulletin S1/2016 contained a further 14 Safety Recommendations in the areas of risk assessment, safety management and aircraft operation at flying displays, to which the CAA responded in FACTOR F4/2016. These Safety Recommendations and their responses are shown in Section 4.2 of this report.

1.18.17 Other relevant Safety Recommendation

AAIB Aircraft Accident Report 6/2009, concerning the accident to Hawker Hurricane G-HURR, contained the following Safety Recommendation:

Safety Recommendation 2009-057

It is recommended that the UK Civil Aviation Authority conduct periodic reviews of the current operating requirements to ensure that they provide adequate safety for display flying.

The CAA accepted this recommendation.

1.19 Investigation techniques

1.19.1 Accident site mapping using an unmanned aircraft system

An unmanned aircraft system was used to obtain aerial images and video of the accident site. The unmanned aerial vehicle (UAV) used weighs 1.24 kg and has a gyro-stabilised camera which can take 14 megapixel stills and 1080p resolution video.

The UAV was used in conjunction with a dedicated software application to fly the UAV in a pre-programmed grid pattern while automatically taking a series of overlapping images with the camera pointing 90° down. A number of flights were conducted at a height of 30 and 50 m.

The images were then processed using photogrammetry software to generate a 3D model and orthomosaic images of the accident site.

1.19.2 Analysis tools

The AAIB analysed the safety system surrounding the accident flight using various techniques including the 'Bowtie' methodology, and methodologies derived from Accimap and Systems Theory Accident Modelling and Process (STAMP).

Bowtie is a barrier risk model used to assist the identification and management of risk associated with an identified loss of system control, known as a "top event". It considers "preventive measures" designed to prevent threats resulting in the top event and "recovery measures" designed to recover control should it be lost or to minimise the consequences should control not be recovered. The model is usually organised as shown in Figure 30.

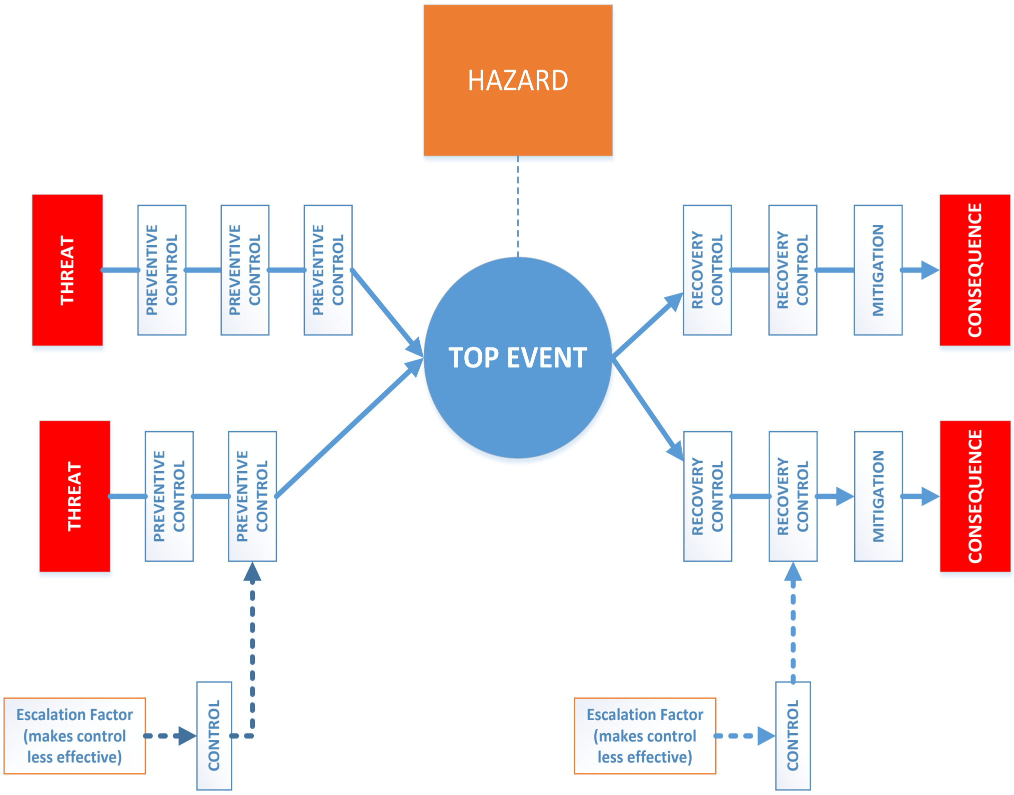

Figure 30

Example Bowtie

The AAIB generated a bespoke Bowtie analysis for this accident informed by the CAA Bowtie templates[71] for 'loss of aircraft control' and 'human factors' and other evidence.

Accimap is an analysis technique based upon the notion that there are multiple layers of causality involved in accidents. Accimap focuses on the causal relationships between layers such as regulatory bodies, technical and operational management and individual operators.[72]

STAMP is an analysis technique, elements of which were used in this investigation to consider adaption and emergence within complex systems.

71 The CAA has developed and published generic Bowtie templates for predictive risk management and illustrative purposes. The AAIB bowtie was developed to assist in considering this specific accident retrospectively.

72 Human Factors Methods A Practical Guide for Engineering and Design. Stanton, Salmon et al.

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2 Analysis

2.1 General

The aircraft was carrying out an aerobatic manoeuvre consisting of both a pitching and rolling component. The available evidence indicates that it reached a maximum height of approximately 2,700 ft, which was below the minimum height required for it to complete the manoeuvre safely. However, the manoeuvre continued and the aircraft struck the westbound carriageway of the A27, Shoreham Bypass, fatally injuring 11 people and injuring 13 others, including the pilot.

This analysis explores why the manoeuvre was not completed safely and why this led to fatal and other injuries to members of the public. Four areas are considered:

1. Aircraft handling. (Section 2.2)
2. Technical issues relevant to the accident flight. (Section 2.3)
3. Control of flying display risk. (Section 2.4)
4. Engineering aspects (Section 2.5)

2.2 Aircraft handling

2.2.1 The accident manoeuvre

The accident manoeuvre was the third in a linked sequence of manoeuvres, following a flypast and a Derry Turn.

The pilot had turned the aircraft between Lancing College and the aerodrome, which was consistent with his plan to reduce the angle at which he would approach the display line and reduce the amount of roll required during the 'bent loop'. In the event, the pilot bent the loop through approximately 60°, which had the effect of positioning the aircraft north-east of the aerodrome with a final track broadly aligned with the A27 instead of the display line[1]. The analysis of aircraft handling during the accident manoeuvre has been divided into two parts:

1. The first half of the accident manoeuvre, from entry until reaching the apex in a near wings level, inverted position.
2. The apex of the manoeuvre.

1 Section 1.18.1 contains a description of a 'bent loop' manoeuvre, the technique for flying it and a description of the pilot's actions during the accident manoeuvre.

2.2.1.1 The first half of the accident manoeuvre

Entry parameters

The aircraft entered the accident manoeuvre approximately 900 m from the display line at a height of 185 ±35 ft. It pitched up into the manoeuvre at an airspeed of 310 ±15 KIAS, less than the minimum entry airspeed of 350 KIAS; the speed below which the pilot stated he would abandon the manoeuvre. The entry was also below the minimum height of 500 ft specified in his DA for aerobatics. The CAA stated in its 1996 Review that it had become common practice for pilots to descend to their authorised flypast height in the middle of an aerobatic sequence, provided they had completed the aerobatic manoeuvre by the specified base height.

Guidance in CAP 403 states:

> *'All aerobatic manoeuvres, including inverted flypasts, and manoeuvres which involve pulling through the vertical are to be executed above the approved aerobatic display height. Descent below the approved aerobatic display height to the approved fly-by height is permitted once certain of capturing the aerobatic display height. Slow speed, high angle of attack flypasts are regarded as aerobatic manoeuvres from the minimum height point of view.'*

The investigation revealed that this guidance is not applied consistently, and that pilots may not understand what is required. Accordingly, the following Safety Recommendation is made:

> **Safety Recommendation 2017-001**
>
> It is recommended that the Civil Aviation Authority amend CAP 403 to clarify the point at which an aerobatic manoeuvre is considered to have been entered and the minimum height at which any part of it may be flown.

Cockpit imaging evidence indicated that the pilot looked down towards the flight instruments four times in the 30 seconds before the aircraft pitched up. However, it was not possible to determine if he looked at the ASI.

Analysis

Had he done so he may have:

- Misread the ASI.
- Read the ASI correctly but recalled the incorrect target speed, possibly substituting the required entry speed for that of another aircraft type.
- Read the ASI correctly and decided to accept the lower speed and continue the manoeuvre; this would have been a departure from his stated technique.

Flight trials demonstrated that entered from 200 ft with an airspeed of 300 KIAS, using T7 equivalent maximum thrust, the aircraft achieved height gains of between 3,200 ft and 3,600 ft in a loop, and between 2,800 ft and 3,200 ft in a bent loop.

Engine thrust

The TP stated that the correct operating technique for the 'bent loop' was to select and maintain maximum thrust. The pilot stated that this was also his technique. However, recorded information indicated that engine thrust modulated during the climb and the maximum thrust available was not achieved.

The examination of the engine (see Section 2.3.2) found that elements of the engine fuel control system had degraded, but concluded there was no evidence to suggest it would not have responded normally to the pilot's inputs. Information included in a previous AAIB report (EW/C98/6/1) indicated that there had been several cases involving the Avon Mk 122 engine where engine speed had reduced and subsequent engineering investigation had not established a clear cause. Were there an un-commanded reduction in engine thrust during the accident manoeuvre it would be best detected by monitoring the engine instruments because a change of thrust may not be detectable audibly. During the climb, the pilot was seen to be looking outside the cockpit and did not appear to look down at the instruments. This suggests that if an un-commanded thrust reduction had occurred he may not have been aware of it.

It was not possible to determine if thrust was modulated by the pilot during the climb because the throttle was not visible in the cockpit image recording during this part of the accident manoeuvre. However, of the two loops recorded during previous displays, where the cockpit action camera captured throttle position, one showed variation of the throttle position during the upward part of the vertical manoeuvre. In that case movement of the throttle correlated with engine speed changes. Throttle position changes can only be made by the pilot, indicating that he had deviated from his stated throttle technique on that occasion. Therefore, whilst mechanical issues cannot be ruled out, it is possible that the variation in thrust during the accident manoeuvre was commanded by the pilot.

2.2.1.2 The apex of the manoeuvre

The pilot looked down towards the general area of the flight instruments on two occasions as the aircraft arrived at the apex of the manoeuvre but it is not known which, if any, of the instruments he observed. The available evidence indicates that the aircraft reached a height of approximately 2,700 ft, which was below the pilot's stated target, at an airspeed of approximately 105 kt, which was slower than normal.

Test flights indicated that the aircraft required a minimum of 2,700 ft to complete the second half of the manoeuvre and that consequently no margin existed for it to do so safely in this case.

The aircraft did not achieve the target parameters at the apex of the manoeuvre because it entered the manoeuvre below the target airspeed and climbed with less than maximum thrust. The maximum height achieved would also have been reduced by any roll initiated before the aircraft reached a vertical attitude in the climb.

At the apex of the manoeuvre the altimeter would have indicated that the aircraft was approximately 800 ft below the minimum height that the pilot stated was required. Tests of the left altimeter indicated that under-reading and lag in its operation may have caused it to indicate an even lower altitude (see Section 2.3.1.1). It was not possible to determine what the altimeter displayed at the apex of the manoeuvre. However, the investigation found that when the altimeter indicated approximately 2,700 ft, the pointer would partially obscure the height counter, which provided the only indication of thousands of feet (see Figure 28).

The pilot stated that if the aircraft achieved a height below 3,500 ft he would perform an escape manoeuvre by reducing the rate of pitch, increasing the airspeed, rolling the aircraft upright and climbing away. The pilot had not practised the escape manoeuvre he described, but the execution of such a manoeuvre would have been consistent with his background and experience.

The RAFCAM HF report identified four reasons why the accident manoeuvre may have been continued:

- The pilot did not check the altimeter.
- The pilot checked the altimeter but did not or could not read it correctly.
- The pilot read the altimeter correctly but did not accurately recall the minimum height required at the apex of the looping manoeuvre for this aircraft.
- The pilot read the height correctly but decided that an escape manoeuvre was no longer possible.

If a false understanding of his height at the apex led him to believe it was sufficient to complete the manoeuvre, he would have had no reason to discontinue it or eject.

2.2.2 Conduct of escape manoeuvres

The pilot was aware of the actions to be taken to escape from a looping manoeuvre when insufficient height was available at the apex to complete it safely. He had not performed that manoeuvre in the Hunter and commented that he would not be sure of the outcome of doing so at airspeeds as low as 105 KIAS. The TP observed that flying an escape manoeuvre was not the same as flying other manoeuvres, such as a half Cuban 8, that the pilot might otherwise have practised.

Flight trials demonstrated that an escape manoeuvre can be accomplished successfully at airspeeds as low as 80 KIAS, and up to four seconds into the descent after passing the apex. The accident pilot stated that he was unsure of these type-specific aircraft handling characteristics and had not practised them. The RAFCAM report stated that four seconds was adequate time within which to make a rule-based decision and implement a practised action but was not sufficient to make analysis-based decisions.

If the pilot had perceived that the apex height was insufficient, it would then have been necessary for him to take the required action to achieve a safe outcome. The available evidence indicates that the pilot had not practised the action required. Therefore the following Safety Recommendation is made:

Safety Recommendation 2017-002

It is recommended that the Civil Aviation Authority require pilots intending to conduct aerobatics at flying displays to be trained in performing relevant escape manoeuvres and require that their knowledge and ability to perform such manoeuvres should be assessed as part of the display authorisation process.

The handling differences between straight-wing and swept-wing jet aircraft introduce the possibility that techniques may be transferred inappropriately from one type to another. Accordingly, the following Safety Recommendation is made:

Safety Recommendation 2017-003

It is recommended that the Civil Aviation Authority review the grouping of aircraft types in display authorisations to account for handling and performance differences it considers significant.

2.2.3 Possible impairment

The investigation considered the possibility that the pilot suffered a cognitive impairment. 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. Action camera evidence from the accident flight and from previous flying displays indicated that the pilot's behaviour and activity did not differ significantly between them.

It is not exceptional for flying display accidents to involve experienced display pilots, and an accident is not necessarily an indication of cognitive impairment.

2.3 Technical issues relevant to the accident flight

2.3.1 Flight instruments

The flight instruments of particular relevance to the investigation were the altimeters, the left airspeed indicator (collectively known as pitot-static instruments) and the engine performance instruments.

2.3.1.1 Pitot-static instruments

It was not possible to test the pitot-static system due to accident damage but there was no evidence of a pre-accident defect. Cockpit action camera recordings showed that the right ASI was providing reasonable indications during the accident flight, suggesting that at least this part of the pitot-static system was functional.

The left ASI was not visible on the cockpit action camera recordings but functioned normally when tested, despite the damage to the instrument glass, and it was determined to be within the required calibration.

The altimeters were not in the field of view of the cockpit action camera during the accident flight. However, during the essentially stable level transit to the south coast the altitude reported by the pilot (probably referring to the left altimeter), the Mode C altitudes and the GNSS altitudes, correlated to within 200 ft of each other, and the magnitude of the differences is not significant to the investigation.

It was not possible to determine whether the left altimeter had been selected to standby or servo mode during the accident flight, however, the pilot was not in the habit of selecting between modes and in the absence of such a selection, the altimeter would be in standby mode by default.

Bench testing of the left altimeter in both modes showed a permanent under-read of 100 ft. The manufacturer stated that this finding suggested the altimeter may have been calibrated incorrectly at build or when last serviced, or that the offset could be attributed to minor slippage within the altimeter gear train due to accident impact forces. In addition, when in standby mode, the displayed altitude lagged the measured altitude due to internal friction and some stickiness of the pointer needle was evident.

The bench testing could not accurately replicate the rapidly changing altitudes experienced in dynamic manoeuvring flight. However, the cockpit video from the Duxford flight in September 2014, showed the STBY flag was present on the left altimeter indicating that it was operating in standby mode during that flight. Therefore it is likely that the stickiness and lag of the pointer needle and the erratic altimeter behaviour exhibited during that flight, was typical of the left altimeter's operation in standby mode during dynamic manoeuvring flight.

Testing also revealed that the right altimeter did not produce the synchronising signal required for the left altimeter to operate correctly in servo mode, due to a defect in its synchro-transmitter. This fault did not trigger the conditions required for the left altimeter to revert automatically to standby mode during testing, and was not among the faults listed in the Aircrew Manual which would cause the left altimeter to revert automatically to standby (see Appendix A).

With this fault, if the left altimeter was selected to servo mode during the accident flight it would have been working independently of the right altimeter, displaying the altitude sensed by its own capsule. The altimeter may have exhibited even greater lag and stickiness than in standby mode, as it would not have benefited from the vibrator motor to overcome friction in the gearing. Its indication would have lagged and then jumped as friction in its mechanism was overcome, and it would have under-read by a minimum of 100 ft. This degraded condition may not have been evident to the pilot, unless close monitoring of both altimeters revealed a discrepancy in their readings.

The broken wire in the right altimeter synchro-transmitter was probably not accident-related but it was not possible to determine how long this fault had existed. The technical records indicated that the right altimeter (S/N 786) was installed in G-BXFI in March 2015, prior to which it had been in an aircraft which had not flown for at least four years. Therefore it is possible this fault existed prior to its installation in G-BXFI. The maintenance organisation stated that it did not keep, or have access to, historic component log cards for the any of the altimeters and was therefore unaware of the component history and last servicing dates.

A pitot-static leak check was carried out following the replacement of the right altimeter. A function test confirming electrical synchronisation between the two altimeters would have identified this fault if present at that time, but was not carried out.

The right altimeter fitted during the Duxford flight had been removed from G-BXFI in March 2015. Subsequent testing, both after removal and later during the investigation, revealed no defects with that unit. In standby mode, the behaviour of the left altimeter would have been independent of whatever altimeter was fitted on the right.

Overall, whether in servo or standby mode, the left altimeter would have indicated a lower altitude at the apex of the accident manoeuvre than the aircraft actually achieved.

2.3.1.2 Rpm indication

The small errors in indicated engine rpm were not considered significant.

2.3.1.3 Jetpipe Temperature (JPT) indication

It was not possible to test the JPT indication system due to accident damage but analysis of recorded data indicated that the system was providing appropriate indications.

2.3.2 Engine and engine controls

The engine manufacturer's analysis of JPT and engine speed, derived from the cockpit action camera recordings, revealed no anomalies during takeoff and transit steady state conditions. There was insufficient data to verify engine performance during the dynamic manoeuvres.

There was no evidence of a pre-impact defect within the engine's compressor, combustion chambers and turbine. It was not possible to determine engine speed at impact, but damage from foreign objects ingested into the compressor and the presence of vegetation within the compressor case bleed air galley confirmed that the engine was operating at impact.

The diaphragm from the hydro-mechanical governor had degraded significantly, having suffered chemical degradation during prolonged periods of inactivity when the fuel system had not been preserved. The laboratory examination of the diaphragm concluded that:

> *'The combined degrading effects of age, exposure to aviation kerosene and air have resulted in the pump diaphragm exceeding the known predictable functional capability of the materials it was manufactured from.'*

The condition of the FCU, the ACU, the BPC and the fuel pump confirmed that they had been subject to normal operational wear, and had not suffered from any pre- or post-impact failure.

The engine manufacturer's analysis concluded that the engine was operating at impact and that there was no evidence to suggest it would not have responded normally to the pilot's inputs. However, information included in a previous AAIB report (EW/C98/6/1) indicated that there had been several cases involving the Avon Mk 122 engine where engine speed had dropped and the subsequent engineering investigation did not established a clear cause. Consequently, an uncommanded thrust reduction could not be ruled out.

2.3.3 Flying controls and hydraulic system

Photographs and video of G-BXFI's display indicated that the operation of its flying controls and the aircraft response to the inputs were normal. Engineering examination of the components did not identify any pre-existing defects.

Analysis

2.4 Control of flying display risk

2.4.1 Analysis methodology

The AAIB Bowtie analysis of this accident considered that the 'loss of system control' occurred when the aircraft reached the apex of the manoeuvre with insufficient height to complete it safely. It explored preventive controls for the circumstances that may have led to this loss of system control, and recovery controls to prevent or mitigate the outcome. In some cases the same controls are represented as both preventive and recovery controls.

The analysis also considered the performance of relevant safety systems and regulation.

2.4.2 Preventive controls

2.4.2.1 Initial and recurrent training programmes

The Hawker Hunter is a high-performance aircraft and appropriate training is vital to its safe operation. It is also an expensive aircraft to operate, with limited engine life, for which a limited supply of spare parts is available. Consequently, it is not unusual for training to be carried out during flights conducted for other purposes to minimise aircraft utilisation.

The training syllabus for an aircraft like the Hunter is devised by the aircraft's operator and forms part of its OCM.

The accident pilot was experienced in displaying RV-8 and Jet Provost aircraft. Aerobatics were not a normal part of his military flying on the Harrier jet, but he was familiar with the recovery from low airspeed and unusual positions experienced in that type during simulated air combat. This experience had some relevance to performing escape manoeuvres during low-level aerobatics, but was not the same as the specific training and demonstration of escape manoeuvres on the Hunter.

The flying training syllabus was proposed by the operator and agreed by the CAA. The exercises were not described in detail and the learning objectives were not specified.

The purpose of training is to transfer skills, knowledge and abilities to the real environment, but in this case the pilot was apparently not aware of relevant aircraft performance within a part of the operational envelope that the aircraft could be reasonably expected to encounter, such as the need to recover from a looping manoeuvre at or near its apex at low airspeed. Whilst the pilot's background and experience of flying aerobatics in jet aircraft had some

Analysis

relevance to performing escape manoeuvres, this was not assessed during his training and testing on the Hunter. Consequently, the initial and recurrent training programs were not an effective control in this case.

Training flights were not recorded by the operator as required by the CAA. The accident pilot had submitted a proposed Training Record form to the Chief Pilot and had completed one for the dual check he carried out on the Chief Pilot, but it was not filed.

The absence of required records is contrary to the obligations placed upon an operator by CAP 632. Accordingly, the following Safety Recommendation is made:

Safety Recommendation 2017-004

It is recommended that the Civil Aviation Authority remind operators, whose activities are subject to the guidance published in Civil Aviation Publication 632, of the need to maintain detailed training records for pilots and check their compliance during inspections it carries out.

2.4.2.2 Pilot currency to maintain proficiency

The pilot had conducted 14 displays and 11 practice displays in the Hunter in the five years before the accident. In 2015 he had conducted one practice and five displays in the Hunter, the most recent being 14 days prior to the accident. The equivalent RAF requirement is to have flown two displays or practice displays on a specific type in the eight days preceding a public display.

The majority of the pilot's jet display flying was in the Jet Provost, which has significantly different performance and lower apex gate heights in looping manoeuvres than the Hunter. His greater experience and recency on the Jet Provost meant that he was more likely to be familiar with the speeds and handling characteristics of this type, and to recall them more easily than those for the Hunter.

2.4.2.3 Operator's procedures

CAP 632 states that *'the more complex and demanding the aircraft, the more detail that will be required in the OCM.'* The operator's OCM had been agreed by the CAA.

Analysis

2.4.2.4 Regulatory requirements for pilot competency

The pilot required an Approved Type Rating Exemption to fly the Hunter. His was valid at the time of the accident but its renewal was based on a statement of his recent flying experience rather than a test or evaluation.

He had renewed his DA in June 2015 in an RV-8 light piston-engined aircraft. This renewal had automatically renewed his DA for all other types including the Hunter, which has significantly different performance and handling characteristics. During his previous renewal in September 2014, flying second in a formation pair of Jet Provosts, he had not been required, nor had the opportunity, to demonstrate his own ability to make decisions or manage the flight path and energy of the aircraft during a display.

Both of these renewals complied with the regulations then in force and were carried out by DAEs authorised by the CAA. However, in neither case had the pilot demonstrated his competence in displaying a Hunter nor, in the 2014 renewal, his ability to conduct a flying display other than when following another aircraft in a formation. Accordingly the following Safety Recommendation is made:

Safety Recommendation 2017-005

It is recommended that the Civil Aviation Authority specify that the flight demonstration requirement of a display authorisation evaluation, other than to assess formation following, cannot be satisfied by the pilot following another aircraft during the evaluation.

The investigation identified that significant differences may exist between aircraft in a given category; for example between swept-wing and straight-wing jet aircraft, or between historic military aircraft and modern aerobatic types. In order to address the potential for transfer of behaviours from a type where they may be appropriate, to another where they are not, such as handling technique, target speeds and gate heights, the AAIB made the following Safety Recommendation in Special Bulletin S1/2016:

Safety Recommendation 2016-041

It is recommended that the Civil Aviation Authority require a Display Authorisation to be renewed for each class or type of aircraft the holder intends to operate during the validity of that renewal.

In FACTOR F4/2016 Issue 2 the CAA responded as follows:

> *'The CAA will review the list of different categories of aircraft relevant to pilot Display Authorisation renewal and assess the impact of operating differences between each category. The CAA will expand this work to include a study of the potential for inappropriate transfer of behaviours between aircraft types. The CAA will consider introducing any relevant findings into the ongoing training and assessment requirements for display pilots, including the requirements for Display Authorisation renewal.*
>
> *The CAA will conclude this review and publish its findings by April 2018.'*

2.4.2.5 Monitoring by the pilot

The available evidence indicates that the information required to determine the aircraft's height, speed and engine performance would have been presented on the aircraft's instruments. The aircraft did not achieve the height and speed that the pilot stated he would require for a 'bent loop'.

The pilot did not recall the accident flight and, although it was not possible to determine why he continued with the manoeuvre when the height at the apex was insufficient to complete it, the investigation identified the four possibilities shown in Section 2.2.1.2. In addition the height and speed achieved was similar to that achieved at the apex of four looping manoeuvres the pilot conducted during two displays in a Jet Provost the previous weekend (see Table 6).

In October 2009 the CAA responded to previous AAIB Safety Recommendation 2009-054 concerning this subject, in part by requiring DAEs to explore human factors in the form of personal limitations and the applicant's mental attitude to display flying, as part of the DA application procedure. CAP 1047 – *'Civil Air Displays – a guide for pilots'*, contains relevant information.

Also, the CAA proposed the following action in CAP 1400 - *'UK Civil Air Display Review'*:

> *'Action 29: The CAA will commence a programme of work to study and enhance understanding of human factor issues within the air display sector, starting with a full-day industry workshop: the causes and impact of human error for display pilots (date to be set).'*

The investigation indicates that further efforts in this area would be beneficial. Accordingly, the following Safety Recommendation is made:

Safety Recommendation 2017-006

It is recommended that the Civil Aviation Authority undertake a study of error paths that lead to flying display accidents and integrate its findings into the human factors training it requires the holders of display authorisations to undertake.

During the investigation two pilots with relevant military and fast jet experience informed the AAIB that they had used an incorrect gate height during a display, or omitted to check that the gate height had been achieved. It is likely that gates will occasionally be missed, reducing the effectiveness of this control and reinforcing the need for other mitigations such as greater performance margins and protection for those positioned beneath the flying display.

2.4.2.6 External monitoring detects the missed gate

The risk assessment for the 2015 Shoreham Airshow, as in previous years, stated that monitoring by the FCC mitigated the hazard of an aircraft crashing outside the airfield boundary. However, the investigation found that monitoring of a display by the FCC is unlikely to be a satisfactory control for this type of occurrence.

Footage of the 2014 display shows G-BXFI overflying the congested areas of Lancing, which appears not to have been detected or acted upon at the time.

During the accident flight, shortly before the pull-up to the accident manoeuvre, G-BXFI was 2 km from the display line, off the airfield and below the pilot's minimum aerobatic height, but the display was not stopped. At the apex of the accident manoeuvre the aircraft was significantly below its gate height, but the FCC did not know the required height and had no way to assess accurately if the aircraft had achieved it. If the FCC had known and been able to intervene by informing the pilot, flight tests indicate that the pilot would have had to perceive the intent of this information, determine that a recovery manoeuvre was necessary, and initiate a recovery manoeuvre, all within four seconds of passing the apex. Therefore this is unlikely to be an effective control.

2.4.2.7 Safety systems and regulation

Safety management systems

A safety management system (SMS) enables an organisation to determine its approach to safety and to identify the hazards to which it is subject. CAP 632 included an SMS evaluation tool. However there was no mention of SMS in

CAP 403 Edition 13 in force at the time of the accident, and no evidence that the available guidance had led to the adoption of SMS or equivalent practices among the operators of displaying aircraft. The operator of G-BXFI was not required to have an SMS and did not have one. The operator of Folland Gnat, G-TIMM also did not have a SMS in place. Likewise, neither the display organiser nor the CAA GAU had, or were required to have, an SMS.

Hazards need to be identified before they can be controlled. The operator's Chief Pilot stated that he had regular discussions with the accident pilot, but he was unaware of the two incidents involving loose articles in the cockpit during displays, which were observed on cockpit camera recordings. A formalised SMS might not have captured these events if the pilot did not report them, but having an effective SMS in place would have provided a mechanism for reporting, and for putting in place safety barriers to counter such events.

The maintenance organisation's Exposition described a QMS but this did not prevent shortcomings in the process intended to ensure that the aircraft was airworthy.

Consequently, at the time of the accident to G-BXFI, the controls that could have been introduced or supported by an SMS were absent.

The CAA GAU has stated that it intends to introduce a regulatory SMS.

Regulation of complex aircraft

The CAA stated that the GAU regulates non-complex aircraft up to a maximum weight of 5,700 kg, including the Hunter which it categorises as an 'intermediate' type. However the Hunter is a 'complex' type as defined by the EASA (see Section 1.18.12) because it is powered by a turbojet engine and has a maximum takeoff mass of 11,340 kg. Therefore the following Safety Recommendation is made:

Safety Recommendation 2017-007

It is recommended that the Civil Aviation Authority review the arrangements for safety regulation and oversight of intermediate and complex ex-military aircraft operated in accordance with Civil Aviation Publication 632, to ensure that they are consistent and appropriate.

Safety culture

A culture of safety involves a willingness to communicate safety issues and evaluate safety related behaviour.

Footage from several flying displays showed low-flying away from the display area and overflight of congested areas that was either not reported or not addressed, and was not confined to one pilot, aircraft or venue. With regard to the operation of G-BXFI, the operator's Chief Pilot was not aware of the presence of loose articles on two flights. The aircraft had been operated for some time with a defective g-meter and defective aileron trim indicator, both of which would have been visible to its pilots. A review of maintenance records indicated shortcomings including non-compliance with mandatory requirements.

Regulatory oversight

The CAA GAU is responsible for regulatory oversight of flying displays in the UK, display pilot and DAE approvals, CAP 632 operator approvals and the oversight of maintenance organisations, including the application of MPDs and the approval of AMOCs.

There was no formalised reporting system related to flying displays and the CAA had not implemented previous relevant AAIB Safety Recommendations that it had accepted.

The CAA GAU did not have mechanisms enabling it to determine the effectiveness of its regulations and how they were applied. Shortcomings included the small number of displays inspected by regulatory staff in 2014 and 2015, the misfiling of some 2014 reports, and the absence of a process for confirming that display organiser risk assessments were of suitable and sufficient quality to ensure that appropriate controls were in place to protect the public.

The AAIB's assessment of the CAA's oversight of the maintenance organisation was hindered because the CAA could not find some of its audit reports.

The CAA GAU relied on informal feedback concerning compliance with DA limits and safety events such as 'stop' calls.

The AAIB made the following Safety Recommendation in Special Bulletin S1/2016:

> **Safety Recommendation 2016-042**
>
> It is recommended that the Civil Aviation Authority publish a list of occurrences at flying displays, such as 'stop calls', that should be reported to it, and seek to have this list included in documentation relevant to Regulation (EU) No 376/2014.

The CAA responded as follows:

> *'The CAA does not accept this recommendation.*
>
> *The CAA is developing a positive reporting culture - a Just Culture – for the air display community. Within the air display sector the CAA believes that this is the most effective way to identify and address potential safety issues before they lead to accidents.*
>
> *In support of this, from April this year the CAA required all event organisers and FDDs to submit, within seven days, a post-air display report to the CAA. This report must include what went well at the display, as well as information on any lapses or breaches from the required standards. Pilots must also report any aspect of their display that could have caused a significant safety risk. The CAA will record all this information. Key information will be shared with the civil air display community through briefings, the pre- and post-season seminars that the CAA jointly hosts with BADA*[2] *and the MAA, and the annual seminar that the CAA organises for DAEs.'*

The AAIB has categorised the response to Safety Recommendation 2016-042 as *'Partially adequate – closed'*, because the proposed system lacks the rigour of a reporting system described in Regulation (EU) No 376/2014, which states:

> *'It is essential to have high-quality and complete data, as analysis and trends derived from inaccurate data may show misleading results and may lead to effort being focused on inappropriate action. In addition, such inaccurate data may lead to a loss of confidence in the information produced by occurrence reporting schemes. In order to ensure the quality of occurrence reports, and to facilitate their completeness, they should contain certain minimum information, which may vary depending on the occurrence category.'*

2 British Air Display Association.

Analysis

Design of the display environment

Every display site has constraints and limitations. The area surrounding Shoreham is particularly congested, with nearly 40% of the surface area within 2 km of the centre of the airport consisting of major roads, housing, industrial or recreational areas. There were areas where secondary spectators were known to gather despite the display organiser's efforts to reduce numbers to address the hazard of road traffic to these crowds. There was also a large bulk fuel storage area 500 m from the north-east end of the display line.

During the 2014 Shoreham Airshow the Hunter flew over some of these congested areas while conducting aerobatic manoeuvres. In Special Bulletin S1/2016 the AAIB reported that infringements of this nature were not confined to one aircraft, pilot or venue.

The risk assessment for the Shoreham Airshow had not considered how individual display aircraft would operate within the constraints of the surrounding area.

In the UK most flying display accidents occur underneath the volume of airspace in which the aircraft is manoeuvring and, in more than half of cases, in areas outside the control of the display organiser.

There was no evidence that the suitability of the specific display sequences intended for the 2015 Shoreham Airshow were considered either in relation to the environment surrounding Shoreham or their effect on uninvolved third parties.

Accordingly the AAIB made the following Safety Recommendation in Special Bulletin S1/2016:

Safety Recommendation 2016-039

It is recommended that the Civil Aviation Authority require the organisers of flying displays to designate a volume of airspace for aerobatics and ensure that there are no non-essential personnel, or occupied structures, vehicles or vessels beneath it.

The CAA did not accept this recommendation.

The normal rules of the air are intended to protect the public in circumstances other than at flying displays by requiring, for example, that aircraft do not perform aerobatics over congested areas or fly closer than specified to any person, vehicle, vessel or structure. It follows that enhanced protection of the public may be necessary only where a displaying aircraft will deviate from those normal rules.

Discussion with the CAA and with flying display participants reveals that an alternative approach to that envisaged in Safety Recommendation 2016-039 is to ensure that aircraft are only permitted to deviate from the normal rules of the air in circumstances over which the participants have control, and for which they have conducted a suitable and sufficient risk assessment.

In Special Bulletin S1/2016 the AAIB made Safety Recommendation 2016-036:

Safety Recommendation 2016-036

It is recommended that the Civil Aviation Authority remove the general exemptions to flight at minimum heights issued for Flying Displays, Air Races and Contests outlined in Official Record Series 4-1124 and specify the boundaries of a flying display within which any Permission applies.

The CAA updated its response to Safety Recommendation 2016-036 in FACTOR F4/2016 Issue 2, as follows:

'The CAA has removed the general exemption to flight at minimum heights issued for civil air displays, air races and contests, outlined in Official Record Series 4-1124.

Display Permissions granted by CAA under Article 86 of the Air Navigation Order 2016 now specify the boundaries of a flying display within which the permission applies.'

Separation distances required at the time of the accident to G-BXFI were based on the 1993 Study, which concluded that the 230 m line was a '*sensible compromise between airshow attractiveness and safety*'. Inspection of the model used by the study revealed that, in the circumstances considered, dense debris such as engines would enter the crowd area in a manner similar to that which occurred at the 1952 Farnborough Airshow.

At the time of the accident there had been no further study to consider more recent concepts such as the debris energy required to cause an injury, the shelter effects of structures or vehicles, or aircraft manoeuvring that has the

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potential to "loft" released components. Accordingly, the AAIB made the following Safety Recommendation in Special Bulletin S1/2016:

> **Safety Recommendation 2016-037**
>
> It is recommended that the Civil Aviation Authority require that displaying aircraft are separated from the public by a sufficient distance to minimise the risk of injury to the public in the event of an accident to the displaying aircraft.

The CAA accepted this Safety Recommendation.

The location of the secondary crowd at the A27/ Old Shoreham Road junction was known to the display organisers. Similar areas exist at other UK display sites. Some members of a secondary crowd may understand the level of risk they are taking but others may be attracted to the area without making that assessment. Accordingly, a minimum level of safety for such areas should be established. The AAIB made the following recommendation in Special Bulletin S1/2016:

> **Safety Recommendation 2016-038**
>
> It is recommended that the Civil Aviation Authority specify the minimum separation distances between secondary crowd areas and displaying aircraft before issuing a Permission under Article 162 of the Air Navigation Order.

FACTOR F4/2016, issued on 9 June 2016, recorded that the CAA did not accept this recommendation. However, following discussions with the AAIB, the CAA included in FACTOR F4/2016 Issues 2 an updated, combined response to Safety Recommendations 2016-037 and 2016-038, as follows:

The AAIB categorised this response as *'Adequate – closed'.*

> *'The CAA will conduct a review, within six months of publication by the MAA of a study by Frazer-Nash, to consider whether any changes are required to the minimum distance that display aircraft are to be separated from the public (primary and secondary crowds) to effectively minimise the risk of injury to the public in the event of an accident to the displaying aircraft. In the event that this study does not deliver a clear output or is terminated, for any reason, the CAA will consider what additional work will be needed to resolve this Recommendation. Subject to the findings of the study and the outcome of the review, the CAA shall make any necessary revisions to the application process for Permissions granted under Article 86 of the Air Navigation Order 2016.'*

Guidance for the risk assessment of flying displays

The report of the HSL highlighted shortcomings in the risk assessment for the 2015 Shoreham Airshow and the AAIB made the following Safety Recommendation in Special Bulletin S1/2016:

> **Safety Recommendation 2016-031**
>
> It is recommended that the Civil Aviation Authority review and publish guidance that is suitable and sufficient to enable the organisers of flying displays to manage the associated risks, including the conduct of risk assessments.

The CAA accepted this Safety Recommendation.

The second study by the HSL, of risk assessment guidance provided by the edition of CAP 403 in force at the time of the accident, found that parts of CAP 403 represented good practice but that the document required improvement.

The CAA issued four revisions to CAP 403 Edition 13 in 2016, and the AAIB has provided the CAA with a copy of the second HSL report. The following Safety Recommendation is made:

> **Safety Recommendation 2017-008**
>
> It is recommended that the Civil Aviation Authority consider implementing the changes outlined in Health and Safety Laboratory report MSU/2016/13 '*Review of the risk assessment sections of CAP 403'.*

Regulation of flying displays

AAIB Aircraft Accident Report 6/2009, concerning the accident to Hawker Hurricane G-HURR, contained the following Safety Recommendation:

> **Safety Recommendation 2009-057**
>
> It is recommended that the UK Civil Aviation Authority conduct periodic reviews of the current operating requirements to ensure that they provide adequate safety for display flying.

The CAA accepted this recommendation. It conducted the UK civil air display review after the accident to G-BXFI, reporting its findings in CAP 1400.

2.4.3 Recovery Controls

When the aircraft failed to achieve the required height at the apex of its manoeuvre, effective recovery controls could have prevented the accident (for example by enabling the pilot to recover the aircraft to level flight before it struck the ground) or mitigated the consequences of the aircraft crashing (for example by separating the crash from public gatherings). The investigation explored six controls relevant to the accident involving G-BXFI:

2.4.3.1 External monitoring detects the missed gate

This control is discussed in the *'preventive controls'* section above. It was ineffective at Shoreham and may not be effective in any case.

2.4.3.2 Pilot performs an escape manoeuvre having recognised it was necessary

This control relies on the pilot's monitoring and training and is discussed in the *'preventive controls'* section above.

This control was not effective in this case.

2.4.3.3 Separate the consequences from uninvolved third parties

At Shoreham, and similar displays in the UK at the time of the accident, there was no specific requirement to separate the displaying aircraft from uninvolved third parties. The CAA considered that separation from third parties would be managed via the risk assessment process; at the time risk assessments were not routinely reviewed by the CAA.

2.4.3.4 Separate the consequences from involved third parties

The investigation found that the display separation distances required at the time would not have protected the crowd from predictable scenarios.

2.4.3.5 Pilot ejects

This control only protects aircraft occupants, leaving no control over where the aircraft or ejection seat impacts the ground. It also relies on the ejection seat system being within its escape parameters and serviceable.

The seat was probably outside its escape envelope for the majority of the flight from the apex of the manoeuvre to impact. Additionally the cartridges in the ejection seat were time-expired and therefore safe ejection could not be guaranteed.

2.4.3.6 Mitigate the risk to first responders

Following the accident to G-BXFI some explosive ejection seat cartridges remained live and phenolic asbestos from the underwing drop tanks was scattered over a wide area. Whilst the ejection seat cartridges were rapidly identified as a risk, the presence of asbestos was not identified until a week after the accident. Until then, emergency services personnel and others were exposed to this hazard. CAP 403 stated that organisers should be aware of hazardous materials used in aircraft and that risk assessments should contain specific mitigation for dealing with aviation materials. The display organisers and the operators of G-BXFI did not have controls to manage the risk from these materials and were either not aware of their presence or were aware but did not inform the emergency services. Other aircraft types that participate in air displays may contain hazardous materials.

The HSE advises that where possible hazardous material should be replaced with non-hazardous material. Therefore the following Safety Recommendation is made:

> **Safety Recommendation 2017-009**
>
> It is recommended that the Civil Aviation Authority require operators of aircraft used for flying displays to identify, and where practicable remove, any hazardous materials.

During the course of the investigation the AAIB were made aware that underwing drop tanks made of materials other than asbestos are available and accordingly the following Safety Recommendation is made:

> **Safety Recommendation 2017-010**
>
> It is recommended that the Civil Aviation Authority prohibit the use of phenolic asbestos drop tanks on civil registered aircraft.

2.4.4 Performance of risk control measures

The investigation found that the only recovery controls capable of preventing a fatal outcome, once the aircraft had failed to achieve the required height at the apex of the manoeuvre, were successful execution of an escape manoeuvre or separation of the accident from the public.

The pilot’s recent training and experience did not equip him to conduct an escape manoeuvre in the Hunter. Measures had been taken to reduce the number of people at the A27 junction for the purpose of minimising the road traffic hazard to these crowds. Measures to mitigate the hazard of aircraft crashing outside the airfield boundary were not effective.

The historic absence of fatal injuries to third parties at UK flying displays does not indicate that the activity is safe.

2.5 Engineering aspects

2.5.1 Engine condition monitoring, maintenance history and regulatory requirements

The use of SOAP as a means of detecting deterioration within oil system components is well established but relies on taking frequent samples to enable a 'baseline' to be defined for the engine. This baseline is then used to identify component deterioration due to changes in the material elements found suspended in the oil. The low oil sampling rate used on G-BXFI would have made SOAP ineffective as a means of monitoring the condition of its engine's oil-wetted components. Furthermore, there was no evidence that the performance of the engine was being formally monitored, thereby reducing the likelihood of early identification of any progressive deterioration in engine performance.

Ageing, and the lack of fuel system preservation during prolonged periods of inactivity, had resulted in degradation of the hydro-mechanical governor diaphragm. Failure of the diaphragm would have resulted in an un-commanded increase in engine fuel flow and possibly engine failure.

The fuel pump was last overhauled in 1998. The current maintenance organisation had been responsible for G-BXFI for approximately three years before the accident, or approximately 12% of the life of the diaphragm. The condition of the diaphragm indicated that deterioration is likely to have been present before the current maintenance organisation had assumed responsibility for the maintenance of the aircraft. The location of the diaphragm meant that its condition could only be verified by physical inspection, which required the disassembly of the fuel pump and governor by an approved overhaul facility.

Due to the age of the engine type and the limited numbers currently operating there has been no capability to inspect or overhaul Rolls-Royce Avon 122 engine fuel control systems for several years. The periods of inactivity of G-BXFI are considered typical of the civil Hunter fleet, and there may be other installed engines of this type in which the hydro-mechanical governor diaphragms have deteriorated.

The fuel control systems of other ex-military gas turbine-powered fixed and rotary winged aircraft may contain components, made from similar materials, whose condition cannot be monitored without specialist facilities. Accordingly, the AAIB presented the findings of the Rolls-Royce laboratory report to the CAA, which resulted in the publication of MPD 2016-001 on 7 October 2016.

The requirements of MPD 2001-001 were intended to mitigate the effects of low utilisation and extended the installed life of Rolls-Royce Avon engines in civil operation. Actions taken by the organisations responsible for G-BXFI's maintenance were capable of identifying deterioration within the gas path and external engine pipes and ducts; they were not capable of identifying the deterioration of compressor blade retention or component deterioration within the engine fuel control system.

The engine type has been in operation for 15 years since the publication of MPD 2001-001, during which unanticipated and unmonitored deterioration may have developed. In addition the aviation industry has introduced new inspection methods that may provide improved detection of engine deterioration.

The AAIB made the following Safety Recommendation in AAIB Special Bulletin S4/2015 published on 21 December 2015:

Safety Recommendation 2015-046

It is recommended that the Civil Aviation Authority (CAA) review the effectiveness of all approved Alternative Means of Compliance to Mandatory Permit Directive 2001-001.

The CAA responded as follows:

'The CAA does not accept this recommendation. There have been no changes to the design of the engine, nor any inadequacy in the effectiveness of associated inspection and monitoring methods identified.'

That position was not supported by the evidence of this investigation. The loss of a compressor blade in a Hawker Hunter T7 in 2013[3], and subsequently the unmonitored deterioration of the fuel pump governor diaphragm, identified during this investigation, demonstrate that maintenance tasks associated with AMOC's to MPD 2001-001 are not able to identify all age-related issues on the Rolls-Royce Avon 122 series of engine.

3 This resulted in the publication of MPD 2016-002 (see Section 1.18.14.4)

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Safety action taken

The CAA published MPD 2016-01, on 7 October 2016, in order to minimise the possibility of an age-related failure of elastomeric components within an engine's fuel control system resulting in an "unsafe condition"[4] in flight. If an aircraft or engine cannot meet the requirements of the MPD an operator or maintenance organisation can apply to the CAA for an AMOC to this MPD. The application must include a failure analysis, based on the MPD guidance material, of all elastomeric components within the engine fuel system. Failures identified as "severe" must include mitigating actions for the failure.

The CAA briefed the investigation on the reasoning and methodology that will be applied to all applications for an AMOC to MPD 2016-01. In recognition that an operator/maintenance organisation may not have a complete understanding of the functionality of such components the CAA has stated that any failure analysis must be completed by someone with a level of specialist knowledge and experience that the CAA find acceptable.

The application of the subsequent MPD 2016-02 is intended to improve detection of compressor blade failure due to age-related deterioration.

FACTOR F1/2016 Issue 2 stated:

> *'The CAA will require ex-military jet aircraft maintenance organisations and/or continuing airworthiness management organisations to conduct a review of their approved Alternative Means Of Compliance (AMOC) to MPD2001-001. Following such a review, each of these affected organisations must make application for a new AMOC in accordance with a new MPD to be issued which will supersede MPD2001-001.*
>
> *The review process will be completed by April 2018.'*

The AAIB re-categorised the response to Safety Recommendation 2015-47 as *'Adequate – closed'*

4 An unsafe condition is defined in MPD 2016-01 as *a "severe failure of an elastomeric component such that continued safe flight and landing would be prevented*".

2.5.2 Compliance with MPD 2001-001

CAA MPD 2001-001 imposes a calendar life limit on the Rolls-Royce Avon of 15 years, and the MPD allows an alternative means of compliance to be approved by the CAA. It states:

> *'The CAA will consider alternative inspection/test and sampling programmes which can be shown to prevent unacceptable deterioration of engines in service. Operators may wish to propose such programmes in lieu of engine withdrawal from service. These programmes must, however, be underwritten by an approved BCAR A8-20 organisation or the manufacturer and must address all ageing related deterioration which could occur on the Avon engine series.'*

In January 2014 the maintenance organisation contacted the CAA with a proposal for an AMOC to MPD 2001-001. The CAA responded that the maintenance organisation should consider including all the items contained in CAP 562 Leaflet 70-80 in any formal submission of an AMOC application. The investigation found no evidence of a further submission.

Prior to publication of AAIB Special Bulletin S4/2015 the CAA stated to the AAIB that it was unclear whether a legally valid AMOC to MPD 2001-001 was in place for G-BXFI at the time of the accident. Following discussions between the CAA and the current maintenance organisation, and a review of G-BXFI's maintenance records, the CAA concluded subsequently that a valid AMOC to MPD 2001-001 had been in place. It reached this conclusion by comparing work that had been carried out by that maintenance organisation with an AMOC that had been documented in the approved Exposition of the previous operator, and not on approvals in place at the time.

The previous maintenance organisation's Exposition, an integral part of its CAA Company Approval, stated in Part Two, *'Procedures Manual'*, Chapter 19, that:

> *'This maintenance programme is the alternative means of compliance with MPD 2001-001 as agreed with the CAA for Avon engines operated and maintained by* [previous maintenance organisation]. *Any deviation to this programme is to be submitted to the CAA for approval'*

CAA document, CAP 562, *'Civil Aircraft Airworthiness Information and Procedures'* – Book 1, leaflet C-30 states:

> *'A CAA Approval once granted is not transferable from one registered company to another.'*

The current maintenance organisation did not have access to the previously approved AMOC to the MPD and did not know the full scope or limitations of the approval. Its inspection program had been based on historic technical log entries annotated with "MPD 2001-001". CAA Airworthiness Division Technical Procedure TP-CAW-18 describes the process for approval of an AMOC. If an applicant can show compliance with a suitable existing AMOC the CAA will issue the applicant with a letter of acceptance, which will be recorded by the CAA. There was no evidence to show that this process had been followed, and on 21 April 2016, the CAA stated:

> *'The CAA did not issue a separate AMOC approval for MPD 2001-001 to* [the aircraft operator] *or* [the current maintenance organisation]*.'*

The engine installed in G-BXFI had exceeded the maximum 15 years since its last overhaul. Neither the operator nor the current maintenance organisation had an approved AMOC to MPD 2001-001, and the aircraft was not compliant with the MPD. Therefore it did not appear to meet the requirements of its Permit to Fly under Article 22 of the ANO 2009.

2.5.3 Ejection seats

2.5.3.1 Initiation of ejection sequence

The cockpit canopy separated from the aircraft shortly after the aircraft struck the road. Photographic evidence indicated that the ejection seat did not leave the aircraft at this point.

There was no evidence from the wreckage examination or the in-cockpit video recording, to indicate that the pilot had attempted to eject or manually jettison the canopy.

The investigation concluded that the ejection sequence was initiated by the mechanical damage resulting from the substantial disruption to the cockpit and seat structure.

Disruption of the bottom fitting prevented normal pressurisation of the ejection gun and initiation of the secondary cartridges. The seat therefore did not have sufficient thrust to clear the aircraft in a controlled manner.

Although only a partial ejection sequence occurred, the seat movement was sufficient to initiate the mechanically-activated aspects of the ejection sequence. This resulted in the deployment of the drogue system and the release of the pilot from the seat. The pilot and his seat were thrown clear of the cockpit while it was still moving, probably by a combination of thrust from the primary cartridge, impact dynamics and the drogues becoming tangled in trees.

The seat came to rest on the ground and the cockpit subsequently overran it. Had the pilot remained attached to his seat it is likely that his injuries would have been more severe.

2.5.3.2 Ejection seat maintenance

There was no evidence that the expired ejection seat cartridges contributed to the initiation of the ejection seat during the impact. However, the investigation made findings about ejection seat maintenance that may be relevant to all civil-operated ex-military aircraft equipped with ejection seats.

The maintenance organisation's decision to extend the installed and total life of the ejection seat cartridges on G-BXFI was not consistent with cartridge lives specified by the seat manufacturer, the published guidance in CAP 632, or the mandatory requirements of the aircraft's AAN. The two-year installed life of the cartridges had been substantially exceeded already by the time the maintenance organisation assumed responsibility for the aircraft, indicating that the use of time-expired cartridges is not unique to one organisation. The maintenance organisation was aware of the cartridge expiry dates but had adopted an informal and undocumented policy of increasing the installed cartridge life to six years. It had not sought formal approval from the CAA to do so and had not followed its own documented procedure with regard to concession control.

The cartridges were first installed in G-BXFI in December 2008 so, at the time of the accident, the two-year installed cartridge life specified by the manufacturer had been exceeded by more than 4½ years and the six-year total life had been exceeded by more than a year. The maintenance organisation's own (unapproved) six-year installation life had also been exceeded by more than one year.

Therefore, it appeared that the ejection seats installed in G-BXFI did not meet the definition of 'fully serviceable' given in CAP 632 paragraph 5.9, nor the requirements of AAN No. 26172 or the Hunter T7 Master Servicing Schedule, and had not done since December 2010.

The maintenance organisation extended the installed and total life of the cartridges based on its assumptions about aircraft utilisation, operating conditions and storage environment but did so with little knowledge of the operating and storage environment of the cartridges prior to becoming responsible for the aircraft in August 2012. It considered the extension of the manufacturer's life limit to be within the privileges granted by its A8-20 maintenance approval.

The ejection seat manufacturer advised that time-expired cartridges can increase the risk of an un-commanded ejection and uncontrolled explosion of the cartridges, or reduce the likelihood of a successful ejection, both of which present a hazard to uninvolved third parties as well as those involved in the operation of the aircraft.

In November 2013 the ejection seat manufacturer informed the CAA of its concerns regarding the use of live ejection seats in civil-operated ex-military aircraft, with specific reference to the use of time-expired cartridges by civilian operators. The CAA response indicated its expectation that these concerns were already adequately addressed by existing guidance, practices and maintenance approvals. The CAA also indicated that it expected operators to adhere to cartridge lives (total and installed) specified by the seat manufacturer and stated that unapproved extension of ejection seat cartridge lives would be considered a 'serious breach' that could jeopardise an organisation's maintenance approval.

Initially the CAA informed the investigation that its written approval was required to authorise any short-term extension of ejection seat cartridge lives, based on technical justification and proof that new cartridges had been ordered. The AAIB informed the CAA that the cartridges installed on G-BXFI were time-expired. After consulting with the maintenance organisation, the CAA informed the AAIB that it was satisfied retrospectively with the decision made by the maintenance organisation to extend the installed life of the cartridges on G-BXFI, despite the absence of a prior CAA approval, a formally documented policy or a technical justification. The CAA based its assertion on the fact that a statement in the organisation's CAA-approved Exposition, not specific to ejection seats, permitted variations to component lives subject to mandatory requirements or ultimate lives not being exceeded in the extension period.

The manufacturer published recommended cartridge lives in a document intended for use by original military operators. The Hunter T7 Master Servicing Schedule, on which G-BXFI's maintenance programme was based, adopted these lives as ultimate lives. All published and internal CAA guidance on ejection seat cartridge lives, including the limitations in G-BXFI's AAN, indicated that the manufacturer's cartridge lives were to be considered a requirement. This position was reiterated in the CAA's correspondence with Martin-Baker.

Interpretation of this issue therefore depends on whether the manufacturer's cartridge life limits are considered a recommendation, or if adoption in the Hunter T7 Master Servicing Schedule, the aircraft's AAN, and guidance in CAP 632 mean they cannot be extended. In the absence of a definitive position, both the existing published CAA guidance on ejection seat cartridge lives, and internal CAA guidance[5], is being applied inconsistently by operators, maintenance organisations and the regulator.

The ejection seat manufacturer's decision in February 2015 to cease the provision of technical support and replacement parts for historic ejection seats may adversely affect the ability of operators and maintenance organisations of aircraft equipped with them to comply with the published cartridge lives in the future. As a result, the manufacturer considers that such ejection seats should be deactivated to prevent the risk of inadvertent operation. Conversely, CAP 632 requires ejection seats in sweptwing aircraft to be fully operational and armed for flight.

Ejection seats provide a means of escape from ex-military jet aircraft whose performance makes a safe forced landing unlikely. However, charged systems such as ejection seats present a hazard to operational and maintenance personnel and to first responders in the event of an accident. It may appear that a decision to continue to operate with time-expired ejection seat cartridges simply hazards the crew who may accept this additional risk, but time-expired cartridges may become unstable and detonate causing the pilot to be randomly ejected from an otherwise serviceable aircraft. This would result in the uncontrolled loss of the aircraft and hazard uninvolved third parties on the ground.

The service and maintenance of ejection seats is a specialist task, but there is no specific CAA maintenance approval for individuals or organisations who perform this task.

In requiring civilian-operated ex-military aircraft to be equipped with live ejection seats, the CAA should consider the benefits of having a means of aircrew escape against the inherent risks presented by such systems. Accordingly, the AAIB made Safety Recommendation 2015-042 (see Section 4.2), which was accepted by the CAA.

5 CAA Airworthiness Division Technical Procedure (TP)-DAW-23-2 *'Ex Military Aircraft on a Permit to Fly'* dated 4 July 2012

2.5.4 Summary of airworthiness findings

The investigation found that G-BXFI was not in compliance with relevant airworthiness requirements. The aircraft engine fuel system had not been inhibited as required by the approved maintenance schedule during periods of inactivity, the engine had exceeded its calendar life without an approved AMOC to MPD 2001-001, and the ejection seat cartridges had exceeded the life limits specified by the ejection seat manufacturer and in the aircraft's AAN. While in operation, limitations were exceeded and not reported, and defects were not recorded. Nevertheless, and despite CAA oversight during the relevant period, a Permit to Fly – Certificate of Validity had been issued on more than one occasion.

In order to provide greater confidence in the airworthiness status of ex-military jet aircraft in the future the AAIB made the following Safety Recommendation in Special Bulletin S4-2015:

Safety Recommendation 2015-047

It is recommended that the Civil Aviation Authority review its procedures to ensure that a 'Permit to Fly Certificate of Validity' is valid when it is issued.

The CAA responded as follows in FACTOR F1/2016, published on 8 April 2016:

'The CAA does not accept this recommendation. The procedure to ensure that a 'Permit to Fly-Certificate of Validity' is valid when issued sits with the approved organisation as set out below. Where a Certificate of Validity is recommended by such an organisation for issue by the CAA, the CAA conducts a quality check to verify the technical and editorial content of the Certificate in accordance with the supporting information provided by the applicant.

An organisation approved by the CAA to conduct an airworthiness review on such aircraft is granted the privilege, under its approval, to declare to the CAA that a particular aircraft complies with the requirements of BCAR Section A Chapter A3-7, which includes completing a physical survey of the aircraft and a documented review of its records to determine its airworthiness status. The CAA, under the current oversight regime, is not required to validate the work carried out under this approval before a Certificate of Validity is issued.

> *An organisation's compliance with these requirements, including the adequacy of declarations, is audited as part of CAA's continued surveillance activity.*
>
> *The current process is consistent with that in place for both National and EASA aircraft operating under a Certificate of Airworthiness.'*

The AAIB categorised the response to Safety Recommendation 2015-047 as *'Not adequate – open'.*

The CAA updated its response to Safety Recommendation 2015-047 in FACTOR F1/2016 Issue 2, stating:

> *'Responsibility for ensuring that a 'Permit to Fly-Certificate of Validity' is valid when issued sits with the approved maintenance organisation and not the CAA. An organisation approved by the CAA to conduct an airworthiness review on such aircraft is granted the privilege, under its approval, to declare to the CAA that a particular aircraft complies with the requirements of BCAR Section A Chapter A3-7, which includes completing a physical survey of the aircraft and a documented review of its records to determine its airworthiness status. The CAA is not required to validate the work carried out under this approval before a Certificate of Validity is issued. Instead, an organisation's compliance with these requirements, including the adequacy of declarations, is audited as part of CAA's continued oversight activity.*
>
> *Therefore, in order to deliver the intent of this safety recommendation, the CAA will review both the design and implementation of its oversight activity in respect of approved maintenance organisations and the process by which documents such as Permit to Fly Certificates of Validity are issued by approved organisations.*
>
> *By April 2018, the CAA will conclude this review, and, should any changes be necessary, identify the date by which they will be implemented.'*

The AAIB re-categorised the response to Safety Recommendation 2015-47 as *'Adequate – closed'.*

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2.6 Governance of flying display activity

Following the accident to G-BXFI the CAA conducted a review of UK civil air displays and determined 29 actions that it has taken or intends to take. Its review was not an investigation of the accident at Shoreham but several of its actions are relevant to it.

The AAIB investigation has identified shortcomings in the conduct and oversight of flying displays in the UK in the areas of operation, risk management and maintenance. It revealed areas of flying display activity in which a culture of safety is not well established and a lack of clarity about who owns the associated risks.

The extent of these shortcomings indicates that a more fundamental review of the governance of flying display activity is required. The AAIB recognises that the CAA GAU is unlikely to have sufficient resources to conduct such a review itself while meeting its ongoing regulatory responsibilities, and that it may be conflicted in doing so. Accordingly, the following Safety Recommendation is made:

Safety Recommendation 2017-011

It is recommended that the Department for Transport commission, and report the findings of, an independent review of the governance of flying display activity in the United Kingdom, to determine the form of governance that achieves the level of safety it requires.

3 Conclusions

(a) Findings

Operational aspects

1. The pilot was licensed and authorised in accordance with the requirements existing at the time of the accident to operate the Hawker Hunter at flying displays.

2. It was the pilot's fifth aerobatic display in a Hunter during the 2015 season and the only public display he carried out that day. He met the recency requirements specified in CAP 403.

3. The accident occurred during a manoeuvre involving pitching and rolling components, intended to be a 'bent loop', at the apex of which the aircraft was inverted.

4. Flight trials indicated that the apex height for a looping manoeuvre with a 90° track change on the upward vertical was 300 to 400 ft less than for a straight loop with all other parameters constant.

5. The accident manoeuvre started and finished outside the aerodrome boundary, over an area not controlled by the organisers of the flying display.

6. A general permission granted by the CAA provided an exemption from the Standardised European Rules of the Air, permitting flight below 500 feet up to 1 km from the display gathering.

7. The pilot's display authorisation for the Hunter stipulated a minimum height for executing aerobatics of 500 ft.

8. The manoeuvre started approximately 900 m from the display line at a height of 185 ±25ft agl.

9. The pilot's declared minimum entry speed for the manoeuvre was 350 KIAS. The aircraft entered the manoeuvre at approximately 310 KIAS.

10. Engine speed varied during the upward first half of the manoeuvre. This was contrary to the pilot's declared technique of using full thrust.

11. The manoeuvre could have been abandoned during its upward first half if an un-commanded reduction in thrust had occurred and been detected.

12. There was no evidence of a pre-existing mechanical defect that would have prevented the engine from responding to pilot throttle inputs. However, the fuel pump governor diaphragm showed significant signs of ageing and chemical attack such that it could no longer be considered airworthy.

13. Information included in a previous AAIB report (EW/C98/6/1) indicated that there had been a number of cases involving the Avon Mk 122 engine where engine speed had dropped and subsequent engineering investigation had not established a clear cause. Therefore, an uncommanded reduction in thrust during the accident manoeuvre could not be ruled out.

14. In tests, the left altimeter under-read by approximately 100 feet. It also exhibited lag and stickiness in its operation both during testing and on a previous flight. Overall, these defects would have resulted in the altitude indicated to the pilot being lower than the actual aircraft altitude at the apex of the accident manoeuvre.

15. The right altimeter had a latent defect which meant it was no longer providing a synchronising signal to the left altimeter.

16. No other technical defects were identified that were relevant to the accident.

17. The minimum height loss during the downward half of a looping manoeuvre in the Hawker Hunter is between 2,600 and 2,950 feet (including 100 ft for instrument reading error), when flown at the values of aircraft mass and density altitude relevant to the accident.

18. The pilot stated that he required a minimum height of 3,500 ft at the apex of the manoeuvre to ensure that he completed it 500 ft or more above the ground (as required by his display authorisation).

19. The aircraft achieved an apex height of approximately 2,700 ft.

20. The airspeed at the apex of the accident manoeuvre was 105±2 KIAS, which was at the lower end of the pilot's declared airspeed range of 100 to 150 KIAS.

21. The aircraft was lower than required at the apex because it entered the manoeuvre below the target airspeed, because less than maximum thrust was applied during its upward half, and because any rolling element initiated before the aircraft reached the upward vertical would have further reduced apex height.

22. The entry height of the manoeuvre was consistent with the 200ft minimum height on the pilot's DA for a Jet Provost; the apex height and speeds on the accident manoeuvre were consistent with those flown in the Jet Provost the previous weekend.

23. The pilot stated that he would abandon a 'bent loop' manoeuvre if the minimum entry speed, or the minimum gate height at the apex, were not achieved. He did not abandon the accident manoeuvre when these minimums were not achieved.

24. It is possible that the pilot misread or misinterpreted speed and height indications during the manoeuvre, or recalled those for a different aircraft type.

25. The pilot had not previously rolled the Hawker Hunter at the low airspeed encountered at the apex, and was not sure that a roll could be achieved at that speed.

26. Flying an escape manoeuvre is not the same as flying planned manoeuvres such as a half Cuban 8.

27. Flight trials indicated that a rolling escape manoeuvre was possible up to four seconds after the aircraft passed the apex of the accident manoeuvre.

28. The pilot had not practised flying escape manoeuvres in the Hunter.

29. The operator's Operational Control Manual did not contain information about performing aerobatic manoeuvres and associated escape manoeuvres.

30. The previous two renewals of the pilot's display authorisation were not performed on the Hawker Hunter.

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

32. The aircraft struck the carriageway of the A27, Shoreham Bypass, in a wings level, nose-high attitude at a speed of approximately 225 kt.

33. The aircraft collided with bystanders, road users and vehicles at the junction of the A27 and Old Shoreham Road, in an area outside the control of the flying display organisers. Eleven people were fatally injured and 13 others, including the pilot, were injured as a result of the accident.

Organisation of the flying display

34. The organiser of the flying display had obtained the permission of the CAA required by Article 162 of the Air Navigation Order (ANO).

35. The CAA, pursuant to Article 162, had permitted the Flying Display Director (FDD) to act as the FDD for the 2015 Shoreham Airshow, having assessed him as 'fit and competent', but had no written policy or procedure for making that determination.

36. The FDD believed that the risk assessment for the flying display was compliant with CAP 403. However, the risk assessment was not suitable and sufficient to manage the risks to the public.

37. The risk assessment did not consider which aircraft would be displaying, where they would operate and to whom they would present a hazard.

38. The FDD did not know the intended sequence of manoeuvres to be flown by the accident pilot, and the edition of CAP 403 in force at the time did not indicate that he should.

39. The risk assessment and risk management guidance provided to display organisers in CAP 403 requires improvement.

40. The risk assessment relied upon compliance with Rule 5 of the Rules of the Air (that no aircraft should fly closer than 500 ft to any person, vehicle, vessel or structure) to mitigate the hazard presented by aircraft displaying over areas outside the control of the organisers.

41. The FDD was not aware that, under a permission granted by the CAA, the aircraft was exempt from this rule when within 1,000 metres of a gathering of persons assembled to witness the event.

42. The CAA did not require to see or approve risk assessments before issuing a permission to hold a flying display in accordance with Article 162 of the ANO.

43. The CAA recommended in CAP 632 that operators of Permit to Fly ex-military aircraft adopt a safety management system (SMS). It did not require them to have one.

44. The operator of the aircraft did not have an SMS or a documented alternative.

45. The General Aviation Unit of the CAA did not have an SMS.

46. The planned display of G-BXFI at the 2015 Shoreham Airshow was similar to that in 2014, in which the location of the aircraft's manoeuvres did not comply with its Permit to Fly.

47. The operator did not have a process to ensure that the manner in which the aircraft was operated during flying displays would comply with the conditions of its Permit to Fly.

48. The CAA did not require persons outside the area controlled by the organisers of the flying display to be protected from the hazards associated with it.

49. The CAA granted the organisers of the 2015 Shoreham Airshow permission to hold a flying display. However, the CAA considers that the principle reason for rejecting an application is safety, and that the proximity of congested areas and heavily used major roads must be taken into account in determining the viability of the site of a flying display. The A27 is a heavily used major road, carrying approximately 58,500 vehicles per day.

50. The organisers of the 2015 Shoreham Airshow recognised that the junction of the A27 with the Old Shoreham Road was a popular gathering point for secondary crowds.

51. Measures taken by the organisers probably reduced the size of the crowd that gathered at the A27 junction, however, there were a number of people standing at the junction of the A27 and Old Shoreham Road during the flying display.

52. Approximately 40% of the land area within 2 km of Shoreham Airport meets the definition of a 'congested area' given in the ANO.

53. The Flying Control Committee had no means of accurately determining the height and speed of displaying aircraft and had to rely on its judgement and experience to monitor their performance.

54. The rescue and firefighting resources in place responded promptly to the accident.

55. The CAA had no means of determining the safety of flying displays other than by attending them. It attended 7% of the flying displays it approved in 2015 and 2.8% of those it approved in 2014.

56. The CAA had not established an acceptable level of safety performance for display flying.

Engineering aspects

Matters related to the accident sequence

57. The pilot did not command an ejection.

58. The aircraft was probably outside the operational envelope of the ejection system during the downward portion of the accident manoeuvre.

59. Activation of the canopy jettison system and the ejection seat was initiated by damage to the cockpit and seat structure sustained during impact.

60. The ejection sequence did not complete due to damage sustained to the ejection seat gun during the impact.

61. The pilot and ejection seat were released from the cockpit during the later stages of the impact sequence and the ejection seat automated release features acted to release the pilot from the seat before it came to rest.

62. Some pyrotechnic cartridges in each of the ejection seats remained live after the aircraft came to rest.

63. Information about the dangers of the ejection seats and other hazards associated with G-BXFI was not available to the organisers of the flying display and therefore could not be passed on to the first responders.

Maintenance and airworthiness

64. The ejection seat manufacturer's recommended installed cartridge life was two years with a maximum total (shelf) life of six years. This recommendation was included as a limitation in the aircraft's AAN, which formed the basis for its certification. The maintenance organisation had adopted a six-year installation life for ejection seat cartridges. This extension to the installed life had not been documented in accordance with the maintenance organisation's procedures, nor had it been approved by the CAA.

65. At the time of the accident, the two-year installed cartridge life had been exceeded by more than 4½ years and the six-year total life had been exceeded by more than a year.

66. The CAA was not aware of the extension to the ejection seat cartridge lives.

67. The CAA did not have a documented procedure for approving extensions to ejection seat cartridge lives but stated that applications for extensions would be considered on a case-by-case basis, and would only be granted for a short period upon proof that new cartridges were on order.

68. The maintenance organisation had new cartridges available, which had not been fitted to the ejection seats in the aircraft.

69. CAP 632 requires the pilot escape systems of swept-wing jet aircraft, such as the Hawker Hunter, to be 'fully serviceable'. The use of time-expired ejection seat cartridges meant that the ejection seats fitted to G-BXFI did not meet this requirement.

70. The practice of using time-expired ejection seat cartridges in civil-operated ex-military aircraft was not confined to G-BXFI or its maintenance organisation.

71. The engine fitted to G-BXFI was not preserved during periods of inactivity as required by the aircraft's approved maintenance program.

72. Neither the operator nor the maintenance organisation had an approved Alternative Means of Compliance with the Mandatory Permit Directive related to engine life (MPD 2001-001).

73. The maintenance organisation did not have access to the previous operator's AMOC. It based scheduled maintenance tasks on entries in the aircraft maintenance records associated with MPD 2001-001.

74. The maintenance organisation submitted a proposal for an AMOC to MPD 2001-001 to the CAA which in turn requested this be resubmitted to include additional tasks detailed in CAP 562 Leaflet 70-80. However, no further application to the CAA was made by the maintenance organisation.

75. The serial number of the right altimeter did not match that recorded in the technical records.

76. Engine rpm exceedences occurring during a test flight in 2011 were not reported or investigated.

77. There was no formal or documented monitoring of engine performance, either during engine ground runs or in flight, which would enable engine performance deterioration to be identified.

78. Video evidence showed that the g-meter fitted to the aircraft was defective during the accident flight and in September 2014. No related defects had been reported or recorded, and the maintenance organisation stated that it was not aware of any.

79. The AAN and Permit to Fly required the fatigue state of the aircraft to be recorded after each day's flight. The maintenance organisation read and recorded the fatigue state once each year; between these readings, monitoring of high fatigue inducing events relied on the pilots reporting high loads seen on the g-meter.

80. The aircraft was being operated with the aileron trim position indicator inoperative.

81. The aircraft had been operated with the flaps extended at speeds exceeding the limit for doing so. This had not been reported in the aircraft technical log.

82. The maintenance organisation issued a Certificate of Validity to the Permit to Fly. At the time of the accident the aircraft did not meet airworthiness requirements or the conditions of its Permit to Fly.

83. CAA oversight of the maintenance organisation and the operator did not identify the deficiencies with the aircraft's airworthiness.

84. The maintenance organisation did not have an established safety management system and was not required to have one.

85. The diaphragm of the fuel pump governor had degraded due to the combined effects of age and chemical attack. The engine manufacturer concluded that it would not have prevented the engine from operating normally but considered that it had exceeded its known predictable functional capability and its continued integrity would be severely affected.

86. MPD 2001-001 was published to mitigate the effects of ageing on the Rolls-Royce Avon series of engines, including the engine fuel systems.

87. The AMOC approved for a previous operator of the aircraft did not include routine inspections of the condition of engine fuel systems. This inspection regime, continued by the current maintenance organisation, did not identify the degradation of the fuel pump governor diaphragm.

88. The aircraft was fitted with underwing drop tanks made from phenolic asbestos. This hazard had not been identified.

(b) Causal factors

- The aircraft did not achieve sufficient height at the apex of the accident manoeuvre to complete it before impacting the ground, because the combination of low entry speed and low engine thrust in the upward half of the manoeuvre was insufficient.

- An escape manoeuvre was not carried out, despite the aircraft not achieving the required minimum apex height.

(c) Contributory factors

- The pilot either did not perceive that an escape manoeuvre was necessary, or did not realise that one was possible at the speed achieved at the apex of the manoeuvre.

- The pilot had not received formal training to escape from the accident manoeuvre in a Hunter and had not had his competence to do so assessed.

- The pilot had not practised the technique for escaping from the accident manoeuvre in a Hunter, and did not know the minimum speed from which an escape manoeuvre could be carried out successfully.

- A change of ground track during the manoeuvre positioned the aircraft further east than planned producing an exit track along the A27 dual carriageway.

- The manoeuvre took place above an area occupied by the public over which the organisers of the flying display had no control.

- The severity of the outcome 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.

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4 Safety Recommendations

The following Safety Recommendations were made in Special Bulletin S4/2015 on 21 December 2015. The CAA responded to each in FACTOR F1/2016, published on 8 April 2016.

4.1 **Safety Recommendation 2015-041:** It is recommended that the Civil Aviation Authority require operators of ex-military aircraft fitted with ejection seats or other pyrotechnic devices operating in the United Kingdom, to ensure that hazard information is readily available which includes contact details of a competent organisation or person able to make the devices safe following an accident.

The CAA responded as follows:

> *'The CAA accepts this recommendation. To ensure that hazard information is readily available for aircraft participating in flying displays, the CAA will amend the certificate supplied to the Flight Display Director by a pilot participating in a flying display to identify the pyrotechnic devices fitted to the aircraft and the contact details of a competent organisation or person able to make the devices safe (or advise on doing so) following an accident. The revised form will be published before the end of April 2016 as part of an amendment to CAP 403.*
>
> *The CAA is currently reviewing how best to ensure that the same information is readily available for aircraft not participating in flying displays. This review will be completed before the end of June 2016.'*

The AAIB has categorised the response to this Safety Recommendation as *'Adequate – closed'.*

4.2 **Safety Recommendation 2015-042:** It is recommended that the Civil Aviation Authority review the guidance in CAP 632 with respect to ejection seats and the means by which operators of ex-military aircraft equipped with them comply with this guidance. This review should include:

- The benefits and hazards of aircrew escape systems in civilian-operated aircraft
- The use of time-expired components
- The availability of approved spares
- The seat manufacturer's guidance on deactivating its historic products
- Adoption of a dedicated Maintenance Approval for persons or organisations competent to perform ejection seat maintenance.

The CAA responded as follows:

> *'The CAA accepts this recommendation and is undertaking a review of ejection seat safety as part of the Air Display Review. This review includes consideration of each of the specific points highlighted by this recommendation and will be completed before the end of December 2016.'*

The AAIB has categorised the response to this Safety Recommendation as '*Adequate – closed*'.

4.3 **Safety Recommendation 2015-43:** It is recommended that the Civil Aviation Authority establish a process for the effective dissemination of ex-military jet aircraft experience and type-specific knowledge to individual maintenance organisations.

The CAA responded as follows:

> *'The CAA accepts this recommendation. By December 2016, the CAA will establish and promote a process for the more effective dissemination of ex-military jet aircraft experience and type-specific knowledge between individual maintenance organisations.'*

The AAIB has categorised the response to Safety Recommendation 2015-043 as '*Adequate – closed*'.

4.4 **Safety Recommendation 2015-44:** It is recommended that the Civil Aviation Authority define a minimum amendment standard for the technical publications for each ex-military jet aircraft type operated on the United Kingdom civil register.

Following the publication of FACTOR F1/2016 Issue 2 the CAA's response is as follows:

> *'Working in conjunction with industry, the CAA will establish a minimum amendment standard for the technical publications for each individual ex-military jet aircraft operated on the UK civil register. The established standard will be recorded in the Airworthiness Approval Note (AAN) for each aircraft.*
>
> *The CAA will complete this work by December 2018.'*

The AAIB has categorised the CAA response to Safety Recommendation 2015-44 as '*Adequate – closed*'.

4.5 **Safety Recommendation 2015-45:** It is recommended that the Civil Aviation Authority require that an ex-military jet aircraft's maintenance programme be transferred with the aircraft when it moves to another maintenance organisation to ensure continuity of the aircraft's maintenance.

Following the publication of FACTOR F1/2016 Issue 2, the CAA's response is as follows:

> *'The CAA is developing a proposal for consultation with industry to introduce a new requirement into BCAR Section A to require a maintenance programme to be transferred with an ex-military jet aircraft if it moves to a new maintenance/continuing airworthiness management organisation, or new owner/operator.*
>
> *Subject to the outcome of the process of industry consultation, the CAA intends to implement this requirement by April 2018.'*

The AAIB has categorised the response to Safety Recommendation 2015-45 as '*Adequate – closed*'.

4.6 **Safety Recommendation 2015-046:** It is recommended that the Civil Aviation Authority review the effectiveness of all approved Alternative Means of Compliance to Mandatory Permit Directive 2001-001.

Following the publication of FACTOR F1/2016 Issue 2, the CAA's response is as follows:

> *'The CAA will require ex-military jet aircraft maintenance organisations and/or continuing airworthiness management organisations to conduct a review of their approved Alternative Means Of Compliance (AMOC) to MPD2001-001. Following such a review, each of these affected organisations must make application for a new AMOC in accordance with a new MPD to be issued which will supersede MPD2001-001.*
>
> *The review process will be completed by April 2018.'*

The AAIB has categorised the response to Safety Recommendation 2015-46 as '*Adequate – closed*'.

4.7 **Safety Recommendation 2015-047:** It is recommended that the Civil Aviation Authority review its procedures to ensure that a '*Permit to Fly-Certificate of Validity*' is valid when it is issued.

Following the publication of FACTOR F1/2016 Issue 2, the CAA's response is as follows:

> *'Responsibility for ensuring that a 'Permit to Fly-Certificate of Validity' is valid when issued sits with the approved maintenance organisation and not the CAA. An organisation approved by the CAA to conduct an airworthiness review on such aircraft is granted the privilege, under its approval, to declare to the CAA that a particular aircraft complies with the requirements of BCAR Section A Chapter A3-7, which includes completing a physical survey of the aircraft and a documented review of its records to determine its airworthiness status. The CAA is not required to validate the work carried out under this approval before a Certificate of Validity is issued. Instead, an organisation's compliance with these requirements, including the adequacy of declarations, is audited as part of CAA's continued oversight activity.*
>
> *Therefore, in order to deliver the intent of this safety recommendation, the CAA will review both the design and implementation of its oversight activity in respect of approved maintenance organisations and the process by which documents such as Permit to Fly Certificates of Validity are issued by approved organisations.*
>
> *By April 2018, the CAA will conclude this review, and, should any changes be necessary, identify the date by which they will be implemented.'*

The AAIB has categorised the response to Safety Recommendation 2015-47 as '*Adequate – closed*'.

Safety Recommendations

The following Safety Recommendations were issued in Special Bulletin S1/2016 on 10 March 2016. The CAA responded to each in FACTOR F4/2016, published on 9 June 2016.

4.8 **Safety Recommendation 2016-031:** It is recommended that the Civil Aviation Authority review and publish guidance that is suitable and sufficient to enable the organisers of flying displays to manage the associated risks, including the conduct of risk assessments.

Following the publication of FACTOR F4/2016 Issue 2 the CAA's response is as follows:

> *'The CAA will review the findings contained in the HSL reports on the management of risk, in conjunction with the conclusions of its post-implementation review of UK Civil Air Displays. The CAA will complete this review and publish any updated guidance by April 2017.'*

The AAIB has categorised the response to Safety Recommendation 2016-31 as '*Adequate – closed'.*

4.9 **Safety Recommendation 2016-032:** It is recommended that the Civil Aviation Authority specify the safety management and other competencies that the organiser of a flying display must demonstrate before obtaining a Permission under Article 162 of the Air Navigation Order.

In FACTOR F4/2016, published on 9 June 2016 the CAA made the following response to Safety Recommendation 2016-032:

> *'The CAA accepts this recommendation.*
>
> *The CAA will specify the safety management and other competencies that the organiser of a flying display must demonstrate before obtaining a Permission under Article 162 of the Air Navigation Order. This will be completed by the end of March 2017.'*

The AAIB has categorised the response to Safety Recommendation 2016-31 as '*Adequate – closed'.*

4.10 **Safety Recommendation 2016-033:** It is recommended that the Civil Aviation Authority introduces a process to ensure that the organisers of flying displays have conducted suitable and sufficient risk assessments before a Permission to hold such a display is granted under Article 162 of the Air Navigation Order.

The CAA responded in FACTOR F4/2016 as follows:

> *'The CAA accepts this recommendation that organisers of flying displays must conduct suitable and sufficient risk assessments.*
>
> *It remains the responsibility of organisers of flying displays to conduct suitable and sufficient risk assessments. The CAA has introduced a new risk assessment process for display applications together with a new risk assessment template and a revised display application form. These are designed to make it clearer to organisers of flying displays the nature of the risk assessment that must be completed. The revised process was published alongside the guidance 'Flying displays and special events: A guide to safety and administrative arrangements' in March 2016.'*

Following the publication of FACTOR F4/2016 Issue 2 the CAA's response to the Safety Recommendation is as follows:

> *The CAA has already introduced enhanced risk assessment guidance to assist event organisers when conducting such risk assessments. The CAA cannot carry out its own risk assessments in respect of every application for a display (and so cannot "ensure" that suitable and sufficient risk assessments have been carried out) and has introduced a process so that, when considering an application for a Permission to hold a display under Article 86 of the Air Navigation Order 2016 (previously Article 162 of the Air Navigation Order 2009), the CAA considers whether the application aligns with the CAA's guidance.*
>
> *The CAA intends also to review the findings of the HSL reports in conjunction with the conclusions of the CAA's own post-implementation review of UK Civil Air Displays in order to consider whether any updated guidance on the management of risk is necessary (see FACTOR response to Safety Recommendation 2016-031 above).*
>
> *The CAA will clarify the responsibilities of organisers / FDDs in this respect during this review and complete and publish any updated guidance by April 2017.*

> *For the 2017/2018 seasons the CAA will review each risk assessment submitted with an application for a display against the specified criteria notified in CAP 403. Where those criteria are not met, the CAA will request further information from the applicant or, where necessary, not grant a permission for that display.'*

The AAIB has categorised the response to Safety Recommendation 2016-31 as '*Adequate – closed'.*

4.11 **Safety Recommendation 2016-034:** It is recommended that the Civil Aviation Authority specify the information that the commander of an aircraft intending to participate in a flying display must provide the organiser, including the sequence of manoeuvres and the ground area over which the pilot intends to perform them, and require that this is done in sufficient time to enable the organiser to conduct and document an effective risk assessment.

The CAA responded in FACTOR F4/2016 as follows:

> *'The CAA understands the intent here is to define the area of ground over which the commander of an aircraft will be permitted to display that aircraft. This can be done in a number of ways. The CAA does not accept that it should specify information in the manner set out in the recommendation. The CAA has concluded that the FDD's risk assessment should be informed by and take account of both the manoeuvres to be flown and the area of ground over which they will be flown.*
>
> *The CAA now requires pilots to confirm to the FDD well in advance of the display briefing that their air display conforms to the air display permission granted by the CAA. If the series of linked manoeuvres or the area of ground over which the aircraft will fly is outside the areas already risk assessed by the FDD, the FDD will be able to take this into account in their risk assessment and document it accordingly.*
>
> *It remains the responsibility of the organisers of flying displays to follow this guidance and conduct risk assessments that are suitable and sufficient to manage the risks associated with the air displays that they are organising.'*

Following the publication of FACTOR F4/2016 Issue 2 the CAA's response to the Safety Recommendation is as follows:

> *'The risk assessment conducted by the FDD is required to be informed by and take account of both the manoeuvres intended to be flown and the area of ground over which they will be flown.*

Safety Recommendations

> *The CAA has amended CAP 403 Appendix B "Certificate to be supplied to the event organiser by a pilot participating in a flying display", to specify the information that the commander of the aircraft intending to participate in a flying display must provide to an organiser in advance of a display, including the manoeuvres intended to be flown. Appendix B must be supplied in sufficient time to enable the event organiser to conduct a risk assessment for the display. The risk assessment (to be submitted with the application for a Permission) must also take account of the ground area over which the display will be performed, which in turn will enable the CAA to specify the boundaries of a flying display within which any permission applies.*
>
> *The CAA has introduced a requirement, in CAP 403 for any pilot intending to fly aerobatic manoeuvres to notify the FDD of the series of the linked manoeuvres that they intend to perform at least one day prior to a display. If the information is not provided, the FDD must not allow the pilot to fly in the display. This information, together with the prior notification of a defined area within which the permission applies, will support the implementation of an effective risk assessment.*
>
> *CAP 403 was amended in June 2016.Completed.'*

The AAIB has categorised the response to Safety Recommendation 2016-31 as 'Partially adequate – closed'.

4.12 **Safety Recommendation 2016-035:** It is recommended that the Civil Aviation Authority require operators of Permit to Fly aircraft participating in a flying display to confirm to the organiser of that flying display that the intended sequence of manoeuvres complies with the conditions placed on their aircraft's Permit to Fly.

The CAA responded as follows:

> *'The CAA accepts this recommendation. The CAA now requires operators of Permit to Fly aircraft participating in a flying display to confirm to the organiser of that flying display that the intended sequence of manoeuvres complies with the conditions placed on their aircraft's Permit to Fly.*
>
> *As set out in the March 2016 edition of the CAA's guidance "Flying displays and special events: A guide to safety and administrative arrangements", all pilots participating in a flying display must*

> *supply the FDD of the air display with a certificate confirming that the display that they intend to perform complies with the conditions placed on the aircraft's Certificate of Airworthiness and Permit to Fly. A template for the certificate is at Appendix B of the guidance.'*

The AAIB has categorised the response to Safety Recommendation 2016-035 as *'Adequate – closed'.*

4.13 **Safety Recommendation 2016-036:** It is recommended that the Civil Aviation Authority remove the general exemptions to flight at minimum heights issued for Flying Displays, Air Races and Contests outlined in Official Record Series 4-1124 and specify the boundaries of a flying display within which any Permission applies.

Following the publication of FACTOR F4/2016 Issue 2 the CAA's response is as follows:

> *' The CAA has removed the general exemption to flight at minimum heights issued for civil air displays, air races and contests, outlined in Official Record Series 4-1124.*
>
> *Display Permissions granted by CAA under Article 86 of the Air Navigation Order 2016 now specify the boundaries of a flying display within which the permission applies.'*

The AAIB has categorised the response to Safety Recommendation 2016-036 as *'Adequate – closed'.*

4.14 **Safety Recommendation 2016-037:** It is recommended that the Civil Aviation Authority require that displaying aircraft are separated from the public by a sufficient distance to minimise the risk of injury to the public in the event of an accident to the displaying aircraft.

The CAA responded as follows:

> *'The CAA understands that this recommendation relates to members of the public attending a flying display.*
>
> *The CAA accepts this recommendation.*
>
> *The MAA has commissioned an independent study into crowd separation distances. This research is ongoing and should report in 2017. As the MAA research is ongoing, the CAA decided in its review of UK civil air displays that, as an interim measure, where*

> *current MAA crowd separation distances are higher it would align with them. The increased distances were announced in April this year in the final report of the CAA's Review of UK Civil Air Displays. The CAA will confirm crowd separation distances after the independent study commissioned by the MAA into crowd separation distances reports in 2017.'*

The CAA subsequently updated its response to this and Safety Recommendation 2016-038 as shown below.

4.15 **Safety Recommendation 2016-038:** It is recommended that the Civil Aviation Authority specify the minimum separation distances between secondary crowd areas and displaying aircraft before issuing a Permission under Article 162 of the Air Navigation Order.

FACTOR F4/2016, issued on 9 June 2016, recorded that the CAA did not accept this recommendation. Following discussions with the AAIB the CAA, FACTOR F4/2016 Issue 2 provided an updated, combined, response to Safety Recommendations 2016-037 and 2016-038, as follows:

> *'The CAA will conduct a review, within six months of publication by the MAA of a study by Frazer-Nash, to consider whether any changes are required to the minimum distance that display aircraft are to be separated from the public (primary and secondary crowds) to effectively minimise the risk of injury to the public in the event of an accident to the displaying aircraft. In the event that this study does not deliver a clear output or is terminated, for any reason, the CAA will consider what additional work will be needed to resolve this Recommendation. Subject to the findings of the study and the outcome of the review, the CAA shall make any necessary revisions to the application process for Permissions granted under Article 86 of the Air Navigation Order 2016.'*

The AAIB categorised this response as *'Adequate – closed'.*

4.16 **Safety Recommendation 2016-039:** It is recommended that the Civil Aviation Authority require the organisers of flying displays to designate a volume of airspace for aerobatics and ensure that there are no non-essential personnel, or occupied structures, vehicles or vessels beneath it.

The CAA responded as follows:

> *'The CAA does not accept this recommendation.*
>
> *The CAA expects the organisers of flying displays and in collaboration with FDDs to identify and then mitigate or manage all the risks to the public arising from their air display. It is for the organiser of the display and the FDD to decide what course of action is necessary and how they will implement it. Furthermore the pilot is responsible for performing their display in accordance with the Permission granted under Article 162 of the Air Navigation Order and their own display authorisation.'*

The AAIB has categorised the response to Safety Recommendation 2016-039 as *'Superseded – closed'.*

4.17 **Safety Recommendation 2016-040:** It is recommended that the Civil Aviation Authority require Display Authorisation Evaluators to have no conflicts of interest in relation to the candidates they evaluate.

The CAA responded as follows:

> *'The CAA does not accept this recommendation as it is impractical to achieve in the relatively small air display community and maintain a working display evaluation system.*
>
> *The CAA believes that it is better to identify any potential conflicts of interest, such as personal or commercial connections, and manage them. In its Action Report of its Review of UK Civil Air Displays, published in January 2016, the CAA strengthened the display authorisation process by requiring, after the first two years, a pilot holding a display authorisation to be revalidated by a different DAE, selected by the CAA. The CAA believes this will reduce the risks of conflicts of interest.'*

The AAIB has categorised the response to Safety Recommendation 2016-040 as *'Partially adequate – closed'.*

4.18 **Safety Recommendation 2016-041:** It is recommended that the Civil Aviation Authority require a Display Authorisation to be renewed for each class or type of aircraft the holder intends to operate during the validity of that renewal.

Following the publication of FACTOR F4/2016 Issue 2 the CAA's response is as follows:

> *'The CAA will review the list of different categories of aircraft relevant to pilot Display Authorisation renewal and assess the impact of operating differences between each category. The CAA will expand this work to include a study of the potential for inappropriate transfer of behaviours between aircraft types. The CAA will consider introducing any relevant findings into the ongoing training and assessment requirements for display pilots, including the requirements for Display Authorisation renewal.*
>
> *The CAA will conclude this review and publish its findings by April 2018.'*

The AAIB has categorised the response to Safety Recommendation 2016-041 as *'Adequate – closed'.*

4.19 **Safety Recommendation 2016-042:** It is recommended that the Civil Aviation Authority publish a list of occurrences at flying displays, such as 'stop calls', that should be reported to it, and seek to have this list included in documentation relevant to Regulation (EU) No 376/2014.

The CAA responded as follows:

> *'The CAA does not accept this recommendation.*
>
> *The CAA is developing a positive reporting culture - a Just Culture – for the air display community. Within the air display sector the CAA believes that this is the most effective way to identify and address potential safety issues before they lead to accidents.*
>
> *In support of this, from April this year the CAA required all event organisers and FDDs to submit, within seven days, a post-air display report to the CAA. This report must include what went well at the display, as well as information on any lapses or breaches from the required standards. Pilots must also report any aspect of their display that could have caused a significant safety risk. The CAA will record all this information. Key information will be shared with the civil air display community through briefings, the pre- and post-season seminars that the CAA jointly hosts with BADA[1] and the MAA, and the annual seminar that the CAA organises for DAEs.'*

1 British Air Display Association

Safety Recommendations

The AAIB has categorised the response to Safety Recommendation 2016-042 as *'Partially adequate – closed'.*

4.20 **Safety Recommendation 2016-043:** It is recommended that the Civil Aviation Authority introduce a process to immediately suspend the Display Authorisation of a pilot whose competence is in doubt, pending investigation of the occurrence and if appropriate re-evaluation by a Display Authorisation Evaluator who was not involved in its issue or renewal.

The CAA responded as follows:

> *'The CAA accepts this recommendation.*
>
> *In its final report of its Review of UK Civil Air Displays, published in April 2016, the CAA announced that where a stop is called because an FDD, or member of the Flight Control Committee, has reason to doubt the fitness or competence of a pilot that pilot will be subject to a provisional suspension of their display authorisation pending an investigation by the CAA of the circumstances leading to the stop being called. In its investigation, the CAA will determine whether the suspension of the display authorisation should be withdrawn or further regulatory enforcement action taken against the pilot concerned.'*

The AAIB has categorised the response to Safety Recommendation 2016-043 as *'Adequate – closed'.*

4.21 **Safety Recommendation 2016-044:** It is recommended that the Civil Aviation Authority establish and publish target safety indicators for United Kingdom civil display flying.

Following the publication of FACTOR F4/2016 Issue 2, the CAA's response is as follows:

> *'The CAA will undertake a study to identify and publish meaningful safety indicators for civil display flying.*
>
> *The CAA will conclude this study and publish safety indicators by September 2017.'*

The AAIB has categorised the response to Safety Recommendation 2016-044 as '*Adequate – closed'.*

The following new Safety Recommendations are made in this report:

4.22 **Safety Recommendation 2017-001:** It is recommended that the Civil Aviation Authority amend CAP 403 to clarify the point at which an aerobatic manoeuvre is considered to have been entered and the minimum height at which any part of it may be flown.

4.23 **Safety Recommendation 2017-002:** It is recommended that the Civil Aviation Authority require pilots intending to conduct aerobatics at flying displays to be trained in performing relevant escape manoeuvres and require that their knowledge and ability to perform such manoeuvres should be assessed as part of the display authorisation process.

4.24 **Safety Recommendation 2017-003:** It is recommended that the Civil Aviation Authority review the grouping of aircraft types in display authorisations to account for handling and performance differences it considers significant.

4.25 **Safety Recommendation 2017-004:** It is recommended that the Civil Aviation Authority remind operators, whose activities are subject to the guidance published in Civil Aviation Publication 632, of the need to maintain detailed training records for pilots and check their compliance during inspections it carries out.

4.26 **Safety Recommendation 2017-005:** It is recommended that the Civil Aviation Authority specify that the flight demonstration requirement of a display authorisation evaluation, other than to assess formation following, cannot be satisfied by the pilot following another aircraft during the evaluation.

4.27 **Safety Recommendation 2017-006:** It is recommended that the Civil Aviation Authority undertake a study of error paths that lead to flying display accidents and integrate its findings into the human factors training it requires the holders of display authorisations to undertake.

4.28 **Safety Recommendation 2017-007:** It is recommended that the Civil Aviation Authority review the arrangements for safety regulation and oversight of intermediate and complex ex-military aircraft operated in accordance with Civil Aviation Publication 632, to ensure that they are consistent and appropriate.

4.29 **Safety Recommendation 2017-008:** It is recommended that the Civil Aviation Authority consider implementing the changes outlined in Health and Safety Laboratory report MSU/2016/13 ‘Review of the risk assessment sections of CAP 403’.

4.30 **Safety Recommendation 2017-009:** It is recommended that the Civil Aviation Authority require operators of aircraft used for flying displays to identify, and where practicable remove, any hazardous materials.

4.31 **Safety Recommendation 2017-010:** It is recommended that the Civil Aviation Authority prohibit the use of phenolic asbestos drop tanks on civil registered aircraft.

4.32 **Safety Recommendation 2017-011:** It is recommended that the Department for Transport commission, and report the findings of, an independent review of the governance of flying display activity in the United Kingdom, to determine the form of governance that will achieve the level of safety it requires.

Appendices

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Appendix A

Altimeter Technical Information

A1 Altimeter system description

General

G-BXFI was equipped with a Mk 29B and a MK 30B Kollsman servo-operated altimeter, mounted on the left and right instrument panels respectively, which received static pressure from the aircraft pressure head.

Altimeters display altitude by comparing the pressure within the sealed altimeter case to the pressure inside an aneroid[1] capsule. As the aircraft climbs and descends, the outside air pressure, and thus the pressure in the altimeter case, changes inversely. The aneroid capsule expands or contracts according to the pressure change. The capsule deflections are converted into rotary motion, by an arrangement of internal gears to drive the pointer on the instrument face and to display the aircraft altitude.

Traditional altimeters can be subject to error and may not accurately respond to rapidly changing altitude, as tiny capsule deflections must overcome friction in the internal gearing, to generate large movements of the pointer. Servo-operated altimeters increase accuracy by using electrical devices such as synchros[2] and servo-motors to amplify and convert the mechanical displacement of the capsule into electrical signals and so drive the pointer.

Mk 30B right altimeter

The Mk 30B[3] right hand altimeter, is a servo-operated encoding altimeter, which displays pressure-corrected altitude. It is an electro-mechanical instrument, relying on a single-phase 115 V a.c. supply from the aircraft electrical system. The Mk 30B operates as the master altimeter, providing an electrical signal to the left (Mk 29B) altimeter and an encoded signal to the aircraft transponder for altitude reporting.

A rocking shaft and gears convert the capsule deflection to rotary motion to drive the rotor of a synchrotel[4], which in turn drives the entire gear train to move the pointer and height counter. The gear train also drives a synchro-transmitter,[5] which sends an electrical signal to the left altimeter; an altitude encoder, which sends a binary signal equivalent to the altitude to the

[1] An aneroid capsule is a sealed, evacuated, thin-walled metal capsule.
[2] A synchro is an electrical device which converts a mechanical input to an electrical output, or vice versa. It comprises a rotating shaft (rotor) and a fixed case (stator).
[3] Mk 30B is the UK military designation for Kollsman altimeter, part number (P/N) L.83261-04-020
[4] The synchrotel amplifies the low torque rotary input from the pressure capsule to rotate an output shaft at high torque, without degrading the accuracy of the input. Unlike a standard synchro, the outer casing of the synchrotel, (stator) , can be rotated mechanically, as well as the rotor.
[5] In a synchro-transmitter, mechanical input (shaft rotation) is converted to an electrical output.

aircraft's transponder; and an adjustable cam, which is calibrated to compensate for known capsule errors at different heights.

Figure A1
Mk 30B altimeter

A setting knob, or 'baro-knob', at the front of the instrument (Figure A1) enables the barometric pressure setting to be set on the four-digit millibar counter. Rotation of this knob corrects the pressure measured by the capsule, and simultaneously rotates the millibar counter, height counter and pointer.

The encoded altitude signal and the synchro-transmitter signal to the Mk 29B are based on a 1013.25 mb datum pressure and are not affected by the setting on the millibar counter.

Mk 30B failure conditions

In the event of a servo malfunction or an electrical power-supply failure to the Mk 30B, a red/black striped power failure flag drops into view to obscure the height counter, and the electrical signals to the Mk 29B altimeter and transponder are disconnected.

The Mk 30B has a Pressure Overload protection feature, so that if the instrument indicates an altitude outside of its operational range, a travel-limit micro-switch will open, and disconnect the electrical supply to the altimeter. The travel-limit micro-switch can also be activated when the altimeter is unpowered if the baro-knob is adjusted upwards by more than 90 mb. This condition is described in the Aircrew Manual as follows:

Appendix A (Cont)

‘Note: If the millibar setting is adjusted with the aircraft power off, the altitude counters and the pointer do not move. If the millibar setting is increased more than 90 mb with AC power off, a travel limit switch within the instrument opens and prevents AC power being connected to the instrument. If the failure flag does not clear when AC power to the instrument is switched on, wind the millibar setting towards the lower end of the scale until the flag clears. Normally only adjust the millibar setting with the power on.’

Mk 29B left altimeter

The Mk 29B[6] left altimeter is a servo-operated altimeter with standby reversion capability to operate as an uncorrected precision pressure altimeter, either automatically or by selection. In normal operation (servo mode), the Mk 29B receives a pressure-error-corrected altitude signal from the Mk 30B, so that it gives a more accurate indication of altitude.

The Mk 29B altimeter mechanism comprises two capsules and their deflections are converted to rotary motion via rocking shafts, which engage with internal gearing to drive the pointer and height counter. A synchrotel and a drag-cup motor are also connected through gearing to the pointer and height counter. The capsule deflections drive the synchrotel rotor.

Figure A2
Mk 29B altimeter in servo mode (left image) and standby mode (right image)

[6] Mk 29B is the UK military designation for Kollsman altimeter, P/N L.82621-04-010

Appendix A (Cont)

When the Mk 29B is operating in servo mode, the synchrotel stator receives a pressure-error-corrected signal from the synchro-transmitter in the Mk 30B and the drag-cup motor is driven by a signal from the synchrotel rotor, based on the capsule deflections. The motor in turn drives the pointer and height counter.

When the MK 29B is in standby mode, the internal gearing is driven only by the capsule deflections, to move the pointer and height counter.

Operation of the baro-knob is similar to that on the Mk 30B.

A STANDBY/RESET knob on the front of the instrument (Figure A2) allows manual selection of the standby or servo mode. The knob is spring-loaded to the centre position. When STANDBY (S) is selected, the altimeter reverts to standby operation. An integral 28 V (d.c.) vibrator motor starts up to help the capsule overcome friction in the internal gearing and an orange STBY flag appears at the side of height counter. When selected to RESET (R) the altimeter resets to servo mode, the vibrator stops and the STBY flag clears. When aircraft electrical power is switched off, the Mk 29B reverts to standby mode.

The Aircrew Manual states that the Mk 29B will automatically revert to standby operation in the event of a primary electrical power failure; a servo amplifier or servo motor failure [in the Mk 30B]; a failure within any part of the [Mk 29B] detection circuit; or, if the difference between the standby capsule altitude and the servo-indicated altitude exceeds a certain level[7].

A note in the Aircrew Manual gives the following advice, to ensure two independent sources of altitude are available for critical phases of flight:

'When the Mk 29B altimeter is being operated in the servo (R) mode, it is possible for a fault in the system to cause both altimeters to indicate the same incorrect height without any warning flag indications. It is recommended, therefore, that the Mk 29B altimeter be selected to standby (S) for take-off and at the beginning of a descent/recovery procedure.'

[7] Differences greater than the pressure equivalent of approximately 4,000 ft at sea level, or up to 10,000 ft at altitude.

A2 Altimeter testing

General

The altimeters had not suffered any obvious external damage during the impact and CT-scans showed no evidence of damage to the internal mechanisms of either unit. However the power failure flag on the Mk 30B appeared to be stuck above the height counter drum. The STBY flag was visible on the Mk29B altimeter, but it was not possible to determine which mode had been selected during the accident flight, as it would have reverted automatically to standby mode upon disruption to the electrical power supply during the impact.

The altimeters were function-tested at the manufacturer's facilities in accordance with the original manufacturer's standard test schedule. Each altimeter was tested in isolation and then both altimeters were connected together, in order to replicate the aircraft installed configuration. In addition the build history for each altimeter was reviewed.

Altimeter build history

Altimeter Mk 29B, P/N L82621-04-010, S/N 1131 was manufactured in 1974 and repaired in 1977. Altimeter Mk 30B, P/N L82621-04-020, S/N 786 was manufactured in 1975 and repaired in 1988. Neither unit had been returned to the manufacturer since then. At the time when the altimeters were built and repaired, instrument build and repair records for military products were only required to be retained for seven years. Consequently such documentation is no longer available.

Mk 29B testing

The Mk 29B failed the manufacturer's test because it exhibited an offset of approximately -100 ft between the actual altitude and the displayed value across its entire range. The manufacturer stated that this finding suggested the altimeter may have been calibrated incorrectly at build or when last serviced. It was also considered possible that the offset could be attributed to minor slippage within the altimeter gear train due to accident impact forces. The effect of this offset is that the Mk 29B would read approximately 100ft lower than the actual aircraft altitude.

The testing also identified a number of anomalies relating to excessive backlash and friction within the mechanical components of the gear train and height counter drum, which resulted in the Mk 29B failing these elements of the test. These anomalies were attributed to wear in the gears and pivots of the gear train and height counter, and were considered to be consistent with expected component wear in an altimeter of this age, which may not have been serviced for many years. The effect of friction is that the displayed altitude could lag the measured altitude. This effect was particularly evident on the Mk 29B when it was tested in standby mode, and more so when the vibrator motor was switched off.

Mk 30B testing

The Mk 30B displayed altitude was within the permissible tolerances across the altitude range, and the encoded signal transmitted to the transponder correctly corresponded to the displayed altitude. However, the Mk 30B failed the test because there was no signal output from the synchro-transmitter. The effect of this would be that, when the Mk 29B was operating in servo mode, the Mk 30B altimeter would not transmit the required electrical signal to the Mk 29B.

The testing also confirmed that the power failure flag was stuck in the open position and did not drop to obscure the drum when the relevant power-failure conditions were met.

Mk 29B and Mk 30B combined testing

The Mk 29B and Mk 30B were connected together using the altimeter wiring loom which had been extracted from the aircraft, in order to observe the effects of the failed synchro-transmitter signal. When in servo mode the Mk 29B did not accurately follow the Mk 30B, but instead displayed values which were lower than the Mk 30B. The Mk 29B pointer and height counter also exhibited some 'stickiness' and did not rotate smoothly. When altitude was increasing, the Mk 29B values were between 180 and 250ft lower than the Mk 30B for altitudes up to 12,500 ft. This discrepancy had increased to 500 ft at 30,500 ft. When the altitude was decreasing, the Mk 29B under-read the Mk 30B by up to 40 ft.

The lack of correlation between the Mk 29B and Mk 30B demonstrated the effect of the absence of the Mk 30B synchro transmitter on the performance the Mk 29B. The Mk 29B under-read was more pronounced when altitude was increasing than when it was decreasing; this hysteresis effect is likely associated with the previously identified friction within the internal gearing of the Mk 29B.

This test was also repeated using workshop test cables to connect the altimeters and the same anomalies were observed, ruling out any faults within the aircraft altimeter wiring loom.

Mk 29B and Mk 30 shop unit combined testing

The Mk 29B from G-BXFI was connected to a fully serviceable Mk 30 shop unit, which was similar to the Mk 30B. When in servo mode, the Mk 29B correctly followed the Mk 30 displayed altitude, albeit with the previously observed approximate -100 ft offset. The Mk 29B pointer and height counter rotated smoothly and there was no lag between the units. This indicated that the Mk 29B functioned correctly in servo mode when it received a valid signal from the master altimeter.

Disassembly of the Mk 30B and the synchro transmitter

Disassembly of the Mk 30B and further testing identified an open-circuit condition across the rotor windings of the synchro-transmitter. It also confirmed that the power failure flag had come off its pivots, most likely as a result of the accident impact.

Disassembly of the synchro-transmitter and examination under a digital stacking microscope, identified that a circlip holding the rotor in place was not fully seated. This may have allowed relative movement of some of the components within the synchro-transmitter. One of the input wires to the rotor winding was observed to be broken and encrusted in a greenish residue. This could account for the open-circuit condition. It was considered that this damage was not accident-related, but there was no means to determine how long this condition had existed.

Mk 30B S/N 993 testing

Mk 30B altimeter S/N 993 was obtained by the investigation for comparative testing. This altimeter had been installed in G-BXFI during a previous flight where some altimeter anomalies were observed but was removed from G-BXFI in March 2015). S/N 993 was tested in isolation and when connected to the Mk 29B from G-BXFI. Its performance was within the permissible tolerances for all aspects of the manufacturer's standard test schedule. No defects were noted with S/N 993, or with the Mk 29B[8] when operating in servo mode connected to S/N 993.

[8] With the exception of the previously observed approximate -100ft offset on the Mk 29B.

Appendix B

Pilot Escape System Technical Information

B1 Description of Ejection Seat

G-BXFI was equipped with two Martin-Baker Mk 4HA ejection seats capable of safe ejection at ground level, providing that the aircraft's flight path is parallel to the ground and it has a forward speed of at least 90 kt. For an aircraft which is descending, the minimum safe height for ejection is approximately 100 ft above ground level, per 1,000 feet per minute rate of descent.

Each seat is mounted on an ejection gun, which uses pyrotechnic cartridges to provide the propellant power for the ejection. The ejection gun is comprised of three telescoping tubes; inner, outer and intermediate. The ejection gun firing unit, which contains the primary cartridge is located at the top of the inner tube. Two secondary cartridges are mounted in the outer tube. The outer tube is attached to the aircraft structure via the 'bottom fitting' which is bolted to the cockpit floor, and a 'top fitting' bracket attached to the rear cockpit bulkhead. The seat is connected to the ejection gun via a spring-loaded plunger, which engages in a locking collar on the inner tube, through a 'top-latch' window on the outer tube. Three sets of steel 'slippers' on either side of the seat structure engage in guide-rails mounted to each side of the outer tube.

Smaller pyrotechnic cartridges are also used in the drogue gun and the guillotine cutter.

The cockpit canopy can be jettisoned by gas pressure from a pyrotechnic cartridge in the canopy firing unit acting upon two pistons, or jacks, which eject the canopy upwards and backwards into the airflow. This can be initiated by pulling the canopy jettison handle at the rear of the centre pedestal. The canopy is also jettisoned automatically whenever ejection is commanded.

In order to make the ejection seats safe for maintenance and to allow safe occupant entry and egress, safety pins are fitted to the firing pins and activation handles of each seat and to the canopy firing unit, when they are not required to be armed. The safety pins are removed from occupied seats prior to flight and placed in a designated stowage.

B2 Normal ejection sequence

Under normal conditions, ejection is initiated by pulling either the face-screen firing handle located above the pilot's head, or the Seat Pan Firing Handle (SPFH), fitted to the front of the seat pan between the pilot legs.

Each firing handle is mechanically connected via cables to a Y-shaped connector, such that when either handle is pulled, two actions happen: the canopy cross shaft rotates to mechanically unlock the canopy and to withdraw the 'sear'[1] from the canopy firing unit, firing the canopy cartridge; and, a sear is withdrawn from the ejection gun time-delay firing unit. After a 0.5 sec delay, which allows sufficient time for the canopy to clear the aircraft, the primary cartridge is fired. The resulting gases pressurise the ejection gun tube, and the recoil pressure forces the inner tube overrides the spring-loaded top-latch, plunger unlocking the seat from the aircraft structure. As the seat accelerates up the guide-rails of the outer ejection gun tube, the inner and intermediate gun tubes are displaced upwards uncovering the two secondary cartridges which fire in turn as they become exposed to the hot gases. Activation of the secondary cartridges increases the ejection thrust and the seat's upward velocity to ensure it clears the aircraft.

As the seat begins to move upwards, leg restraint lines pull tight to prevent occupant leg injury. As the seat leaves the aircraft the shear rivet attaching each leg restraint line to the cockpit floor shears. The ejection gun remains attached to the aircraft structure.

While the seat is rising two static telescopic rods, mounted on either side of a bracket at the rear of the seat, are activated simultaneously. One of the static rods withdraws the sear from the drogue gun, setting a time-delay mechanism into operation. After a 0.5 second delay the drogue gun cartridge fires and a piston (drogue gun bullet) is ejected, carrying with it the drogue withdrawal line and the 22 in controller drogue. The controller drogue then extracts the main 5ft drogue and the two drogues inflate to retard and stabilise the seat as it falls.

The other static rod withdraws the sear from the Barostatic Time Release Unit (BTRU). After a time delay of 1.25 seconds the harness-release plunger extends which releases ejection seat scissor shackle, the pilot's harness locks and the leg restraint lines. The pull of the main drogue is transferred from the scissor shackle to the parachute withdrawal line, extracting the auxiliary parachute and main parachute canopy and separating the pilot from the seat. Once the main parachute canopy is deployed the pilot is rapidly decelerated and can descend under the parachute and the seat falls away separately. An integral barostat delays operation of the BTRU until the seat is below 10,000ft and is at a safe speed

If the seat fails to eject or if the BTRU does not function correctly to achieve automatic man-seat separation following ejection, a manual separation handle on the port side of the seat pan can be pulled and this will release the locks securing the pilot's harness to the seat and the leg restraint lines. As the seat, which is still attached to the drogue parachute, falls away from the pilot a cable between the pilot's parachute and the seat is pulled, removing the sear from the guillotine firing unit. When the cartridge fires a small guillotine blade is forced upwards, severing the line connecting the main drogue to the main parachute canopy. The pilot is then fully separated from the seat and drogues, and will have to manually pull the parachute rip-cord handle to deploy the main parachute canopy.

[1] A sear is part of the firing mechanism which holds back the firing pin, until the correct amount of pressure has been applied, at which point the pin is released firing the cartridge.

The guillotine is also fired during normal automatic separation, but the parachute withdrawal line is pulled out of the guillotine gate by the force of the drogues being deployed before the cartridge is initiated.

B3 Examination of Ejection seats

B3.1 Pilot's (left) seat

The pilot's seat was lying face-down on the ground, underneath the main cockpit wreckage. The seat pan had partially separated from the seat-back and the seat's main beam assembly was fractured in a number of locations.

During the operations to make safe the ejection seats at the accident site, it was identified that the left seat primary ejection gun cartridge, drogue gun cartridge and guillotine cartridge had fired, but the two secondary ejection gun cartridges had not. The BTRU harness release plunger was extended and the scissor shackle was released, indicating the BTRU had operated. The canopy jettison cartridge had also fired.

Two of the left ejection seat safety pins were found in the designated cockpit stowage, and a third was recovered from the accident site. It is likely that the remaining safety pins were dislodged from the stowage during the accident sequence. A photograph taken prior to G-BXFI's departure from North Weald, showed that the left ejection seat and canopy jettison safety pins had been removed and stowed correctly, as would be expected for flight in the occupied condition.

The seat pan firing handle (SPFH) was stowed within its housing, indicating that it had not been pulled. The face-screen handle was found in the wreckage having been fully removed from, but lying close to, its housing in the ejection seat's drogue container.

The ejection gun had suffered major structural damage at its base. Although the bottom fitting remained bolted to the cockpit floor, the fitting had fractured, compromising the bonded joint with the outer ejection gun tube, such that the entire gun assembly had separated from the bottom fitting and was unrestrained. The bottom 33 cm of the inboard guide-rail had broken off. The outboard guide-rail in the corresponding area had a large dent and some attachment rivets had sheared off.

The intermediate and inner gun tubes remained within the outer tube, but had not fully extended. The circular bracket attaching the ejection gun to the top fitting had sheared on one side. The spring-loaded plunger had over-ridden the top-latch window and there were a number of damage marks around the top-latch window.

One of leg restraint lines remained attached to the cockpit floor at one end, indicating the shear rivet had not experienced sufficient load to cause it to fail, the other end having pulled through the snubbing unit. The other leg restraint line had sheared from the cockpit floor, but the line had also been pulled through the snubbing unit and was found lying near the seat.

The 22in and 5ft drogues had been extracted from their housing and were entangled with cockpit wreckage and tree debris. The drogues had not inflated and were still folded. The drogue-to-parachute withdrawal line had been severed by the ejection seat guillotine. The manual separation handle had not been operated.

The main parachute had remained within its container, but the auxiliary parachute had been fully extracted. The rip cord handle was found stowed and had not been operated.

B3.2 Right hand seat

The right-hand ejection seat remained inside the cockpit. The circular bracket attaching the ejection gun to the top fitting was sheared on both sides, leaving the seat and ejection gun free to tilt forward, pivoting about the ejection gun bottom fitting. The seat was also free to slide up the ejection seat guide-rails as the spring-loaded plunger had been forced through the top-latch window, fracturing the top of the top-latch window.

The drogue gun cartridge and guillotine cartridge had fired but primary and secondary ejection gun cartridges had not. The BTRU had operated and released the parachute locks. The parachute withdrawal line had been severed by action of the ejection seat guillotine.

The 22in drogue had been ejected by the drogue gun and the 5ft main drogue was partially withdrawn from its container. The main parachute remained within its parachute container.

The four ejection seat safety pins remained installed, as would be expected in an unoccupied seat.

B4 Analysis relating to initiation of ejection sequence

The cockpit canopy separated from the aircraft shortly after the aircraft struck the road. In a normal ejection sequence the ejection gun would fire 0.5s after canopy jettison and the ejection seat would be ejected out of the aircraft. Photographic evidence indicated that the ejection seat did not leave the leave the aircraft at this point.

The SPFH on the left seat was intact and there was no evidence from the in-cockpit video recording to indicate that the pilot had attempted to pull the face-screen handle to initiate ejection prior to or during the impact sequence. Although the face-screen handle had been extracted from its stowed position, this most likely occurred during the break-up of the cockpit structure and extraction of the drogues.

Neither was there any evidence that the pilot had attempted to manually jettison the canopy. It was therefore concluded that the ejection sequence was initiated by the mechanical damage resulting from disruption to the cockpit and seat structure.

The impact sequence resulted in substantial disruption to the cockpit floor, which was forced upwards causing severe disruption to the left seat ejection gun bottom fitting, upwards displacement of the seat, and partial failure of the top attachment bracket. The damage to the

Appendix B (Cont)

guide-rails also indicated that the left seat had experienced a sideways impact, most likely from trees or other obstacles.

The impact loads transmitted through the right hand seat caused total failure of its top attachment bracket, leaving the seat and ejection gun free to tilt forward and the seat unrestrained on the guide rails.

The upwards displacement of either seat, or indeed the forward displacement of the right seat, would have placed the cables to the canopy firing unit under tension, thereby initiating canopy jettison. Similarly the upwards displacement of the left seat would have placed the ejection seat initiation cable under tension, firing the primary cartridge.

The disruption to the bottom of the left seat ejection gun allowed the hot gases generated by firing primary cartridge to be vented to atmosphere preventing pressurisation of the ejection gun. As a result, the inner tube failed to fully extend and the secondary cartridges were not exposed to the hot gases required for them to fire. Therefore the seat did not have sufficient thrust to clear the aircraft in a controlled manner.

Although only a partial ejection sequence occurred, the resulting upwards momentum of the seat was sufficient to release the seat from the ejection gun. The seat movement also initiated the mechanically-activated aspects of the ejection sequence, deploying the drogues and releasing the scissor shackle, harness locks and leg restraints.

The drogues did not fully develop due to the aircraft's decaying speed during the impact sequence and instead became entangled in trees and aircraft wreckage. The pilot and his seat were thrown clear of the cockpit while it was still moving. The unrestrained seat was thrown from the cockpit most likely due to a combination thrust from the primary cartridge, impact dynamics and the drogues becoming tangled in trees.

As the drogues did not develop the main parachute was not extracted and the parachute withdrawal line remained in the guillotine gate, instead of being pulled clear. Once the harness locks had released the relative displacement between the pilot and his seat caused the guillotine to fire, separating the pilot from seat and the drogue system. The seat came to rest on the ground before the cockpit did and the cockpit subsequently landed on the seat. Had the pilot remained attached to his seat it is likely that his injuries would have been much more severe.

Appendix C

Permit to Fly

Certificate No:

PR 048467/006

UNITED KINGDOM
CIVIL AVIATION AUTHORITY

PERMIT TO FLY

Civil Aviation Authority

Nationality and Registration Marks	Constructor and Constructor's Designation of Aircraft	Aircraft Serial Number
G-BXFI	**HAWKER AIRCRAFT LTD** **HAWKER HUNTER T7**	**41H-670815**

Engine: ROLLS-ROYCE AVON MK 122 **Propeller: N/A**

This Permit to Fly, issued pursuant to the Air Navigation Order, hereby permits this aircraft to fly within United Kingdom airspace only without a Certificate of Airworthiness being in force in respect thereof. This permission for flight within United Kingdom airspace does not constitute a Certificate of Airworthiness issued pursuant to the Convention on International Civil Aviation dated 7 December 1944.

This Permit to Fly is issued subject to the associated Conditions.

EXEMPTION

The Civil Aviation Authority in exercise of its powers under the Air Navigation Order, hereby exempts this aircraft from the provisions of the said Order which prohibits an aircraft flying in accordance with the conditions of a Permit to Fly, from flying on any flight which does not begin and end in the United Kingdom without passing over any other country. **This exemption is granted subject to the condition that before flying within any other country, permission is obtained from the appropriate authority of that country.**

A CERTIFICATE OF VALIDITY FORMS PART OF THIS PERMIT TO FLY

The Certificate of Validity will be renewed by the Civil Aviation Authority, following a recommendation based on a satisfactory airworthiness review by an organisation approved in accordance with BCAR A8-20. The Certificate of Validity will remain valid for the period prescribed from the date of issue.

Date: **17 OCTOBER 2003**

CIVIL AVIATION AUTHORITY

for the Civil Aviation Authority

No entries or endorsements may be made on this Permit or the Certificate of Validity except by an authorised person. If either document is lost, the Civil Aviation Authority should be informed at once. Any person finding these documents should forward them immediately to the Civil Aviation Authority, Safety Regulation Group, Aviation House, South Area, Gatwick Airport, West Sussex, RH6 0YR.

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Appendix C (Cont)

UNITED KINGDOM
CIVIL AVIATION AUTHORITY

Civil Aviation Authority

Page 1 of 3

Dated: 17 OCTOBER 2003

CONDITIONS OF
PERMIT TO FLY NO PR 048467/006

Nationality and Registration Marks	Constructor and Constructor's Designation of Aircraft	Aircraft Serial Number
G-BXFI	**HAWKER AIRCRAFT LTD** **HAWKER HUNTER T7**	**41H-670815**

Where relevant, the Conditions associated with this Permit supersede those specified in the manufacturers' operating limitations.

1. The aircraft shall not be flown over any assembly of persons or any congested area of a city, town or settlement, except to the extent necessary in order to take-off and land at a Government or licensed aerodrome in accordance with normal aviation practice.

2. A Permit Maintenance Release shall be issued as appropriate in accordance with BCAR A3-7.

3. The aircraft shall be maintained by an Approved Organisation (BCAR A8-20) in accordance with a recognised maintenance programme/schedule based on the manufacturer's and/or the previous military authority's published maintenance requirements.

4. The aircraft shall be operated in accordance with the relevant Pilots Notes, Aircrew Manual or the manufacturer's prescribed operating limitations and requirements. Where applicable, the aircraft shall be operated in accordance with CAP 632 (Operation of 'Permit-to-Fly' Ex-Military Aircraft on the UK Register).

5. Maximum number of occupants
   5.1 Maximum number of occupants authorised to be carried (including crew): Two
   5.2 The minimum flight crew is One pilot(s).

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960P/C1
290703

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Appendix C (Cont)

UNITED KINGDOM
CIVIL AVIATION AUTHORITY

Page 2 of 3

Dated: 17 OCTOBER 2003

CONDITIONS OF PERMIT TO FLY NO PR 048467/006

Civil Aviation Authority

Nationality and Registration Marks	Constructor and Constructor's Designation of Aircraft	Aircraft Serial Number
G-BXFI	**HAWKER AIRCRAFT LTD** **HAWKER HUNTER T7**	**41H-670815**

6. The aircraft must be operated in compliance with AP 101B-1302 and 3-15; Aircrew Manual together with the following operating limitations, which shall be displayed in the crew compartment by means of placards or instrument markings:

6.1 Aerobatic Limitations
Aerobatics are permitted in accordance with Pilots Notes.
Flick manoeuvres and intentional stalling and spinning are prohibited.
Load factor limitations: +7.0 / -3.75 g. Negative g is limited to 10 seconds duration only.

WARNING: This aircraft displays many of the deficiencies in stability of the original type design; all manoeuvres likely to lead to an inadvertent departure from controlled flight are prohibited.

6.2 Engine Limitations – (see AP 101B-1302 and 3-15)

RATING	RPM	JPT(°C)	DURATION
Take-off:	8100	690	10 minutes
Intermediate:	7950	655	30 minutes
Maximum Continuous:	7700	625	-
Minimum Approach:	4500	-	-

6.3 Air speed Limitations – (see AP 101B-1302 and 3-15)

Maximum speed, power boosted controls on:		620 knots
Maximum speed, manual controls below 15,000 feet:		0.75 Mach (0.85M above 15,000 feet)
Undercarriage operation/deployed:		250 knots
Flaps:	0° to 38°:	300 knots (or 0.9M)
	>38° and fully down:	250 knots

6.4 Other Limitations:
Smoking in the aircraft is prohibited.

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290703

Appendices

Appendix C (Cont)

UNITED KINGDOM
CIVIL AVIATION AUTHORITY

Page 3 of 3

Dated: 17 OCTOBER 2003

CONDITIONS OF
PERMIT TO FLY NO PR 048467/006

Civil Aviation Authority

Nationality and Registration Marks	Constructor and Constructor's Designation of Aircraft	Aircraft Serial Number
G-BXFI	HAWKER AIRCRAFT LTD HAWKER HUNTER T7	41H-670815

7. Loading Limitations

Maximum take-off:	11340 kg (25,000 lb)
Normal landing:	8392 kg (18,500 lb)
Emergency landing:	10614 kg (23,400 lb)

C of G to be between 1.0 inches forward of datum and 14.5 inches aft of datum.
Datum is marked by a spigot in the port main undercarriage bay.

8. Additional Limitations
Reliance is not to be placed upon the brake parachute when planning a landing. It is not to be streamed before touchdown and a speed limit for streaming is 160 knots.
Fatigue is to be accounted in accordance with section 4.2 of AAN 26172 after each days flight.

for the Civil Aviation Authority

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960P/C2
290703

Appendix D

Log Card for the High Pressure Fuel Pump

COMPONENT RECORD CARD (Revised Feb 80)

1 AUTHORISED LIFE

2 TRANSFER AND INSTALLATION DETAILS

Date	Unit From	Unit to/ Installed in/ Removed From	Life Consumed of Support Installation	Life Consumed of Component: Part	Life Consumed of Component: Total	Authority for Transfer/ Reason for Removal
24.7.88	LUCAS	ECU 2882	180.10	NIL	NIL	
17.8.88	Rolls Royce plc E.K.	ECU.2882.	180.10		NIL	Allot. No. 98018.
23.8.89	Rolls Royce PLC. E.K	ECU 2882	450.05		269.55	Allot No:
20.2.90	Rolls Royce Plc E.K.	ECU.2882	450.05		269.55	Allot. No. 96303

9

Section	Reference.	Description	Serial No	Installed In	Limiting Item	Due Removal
		H.P. FUEL PUMP G7064/1A	B3594R			

Appendix E

Strip Examination and Assessment of Avon MK122 SN 41H-670815

Security classification#01
Private – Rolls-Royce Data

Rolls-Royce

TECHNICAL REPORT

Discipline or report series#10	Document number#12	Report number#52	Issue#13
Air Safety Investigation		EFI/1186	1

Title#15
Strip examination and assessment of Avon Mk122 s/n 41H-670815 installed in Hawker Hunter T7 reg G-BXFI Shoreham Airport on 22nd August 2015.
Authority:

Authors#20	Telephone:	Date#40
[redacted]	[redacted]	22/03/2016

Summary#60
On the 22nd August 2015 Hunter T7 aircraft s/n G-BXFI departed its home base at North Weald in Essex for an air display at Shoreham Airport in West Sussex. Not long after the start of the display the aircraft did not achieve level flight after a vertical manoeuvre and struck the westbound carriageway of the A27

The AAIB were informed of the accident and initiated a field investigation. The AAIB requested Rolls-Royce Air Safety Investigation Department assistance in the investigation. This report details the strip and technical examination of the engine and its accessory units. The report also includes an assessment of engine performance conducted by the Rolls-Royce performance department.

Strip examination of the engine found that its condition was commensurate with its age with no evidence of any pre-accident anomalies.

Debris found within the core of the engine was consistent with the engine operating at the point of impact.

Detailed strip examination of the engine accessory units found nothing that would prevent the engine from operating across its full speed range.

Laboratory examination of seals and diaphragms from the accessory units found that some had evidence of age degradation. However, there was no suggestion that seal or diaphragm integrity had been compromised or that they would have prevented the engine from operating normally.

Comparison of engine speed data obtained via spectral analysis with video evidence of engine operating temperatures indicates that the engine appeared to be operating in a stable manner throughout the incident flight.

A performance assessment has found that the engine was performing as expected and that no major performance changes were evident.

Throttle lever position during the event sortie could not be established therefore it has not been possible to determine if the level of thrust delivered by the engine matched that demanded by the pilot

Additional keywords#90	Retention category
	A

Circulation:	Approved by:
Alan Thorne, UK AAIB	See report signature section

Project	Sub-system	Process	Part number
Avon	Whole engine		
Engine types#24	**Engine marks/vehicle name**	**Vehicle number/build#28**	**Module**
Avon	Mk122 / Hawker Hunter T7	G-BXFI	

Material	Design definition	Design def. issue	CTP#32	ATP#36	Dept#44	File/folder#48
						EFI/1186

Security classification#01
Private – Rolls-Royce Data
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TABLE OF CONTENTS

1 ABBREVIATIONS AND ACRONYMS

AAIB:	Air Accident Investigation Branch.
ACU:	Acceleration Control Unit
ASI:	Air Safety Investigation
BPC:	Barometric Pressure Control
FCU:	Fuel Control Unit
ft:	Feet.
HMG:	Hydro Mechanical Governor
HP:	High Pressure
IIC:	Investigator In Charge
IRHD:	International Rubber Hardness Degrees
ISA:	International Standard Atmosphere
JPT:	Jet Pipe Temperature
KIAS:	Knots Indicated Air Speed
LP:	Low Pressure
OAT:	Outside Air Temperature
OEM:	Original Equipment Manufacturer
rpm:	Revolutions per Minute
SLS:	Sea Level Static
s/n:	serial number
UTAS:	United Technologies Aerospace Systems

Appendix E (Cont)

2 COMPONENT DETAILS

Subject Avon Mk122	**Aircraft Type & No.** Hunter T7 / G-BXFI	**Authority** N/A
Part No. N/A	**Engine Type & No.** Avon Mk122	**Contract No.** N/A
Serial No. 41H-670815	**Operator**	**SAP No.**
Hours TSN 1222	**Location** Shoreham Airport	**Incident Date** 22nd August 2015
Manufacturer Rolls-Royce	**F760 Report & Date** N/A	

3 REASON FOR INVESTIGATION

On the 22nd August 2015 Hunter T7 aircraft s/n G-BXFI departed its home base at North Weald in Essex for an air display at Shoreham Airport in West Sussex. During part of the display sequence a manoeuvre containing both a vertical and rolling component was conducted, at the apex of which the aircraft became inverted. Following the subsequent descent the aircraft did not achieve level flight before striking the westbound carriageway of the A27.

The AAIB were informed of the accident and initiated a field investigation.

4 EXTENT OF INVESTIGATION

Rolls-Royce Air Safety Investigation Department were made aware of the accident and a request for assistance was made by the AAIB. Rolls-Royce ASI personnel were subsequently detailed to technically assist the AAIB as required by their investigation.

On the 3rd September 2015 ASI visited the AAIB in Farnborough where an initial investigation meeting was held followed by a visual assessment of the wreckage.

4.1 Initial Engine Inspection / Examination

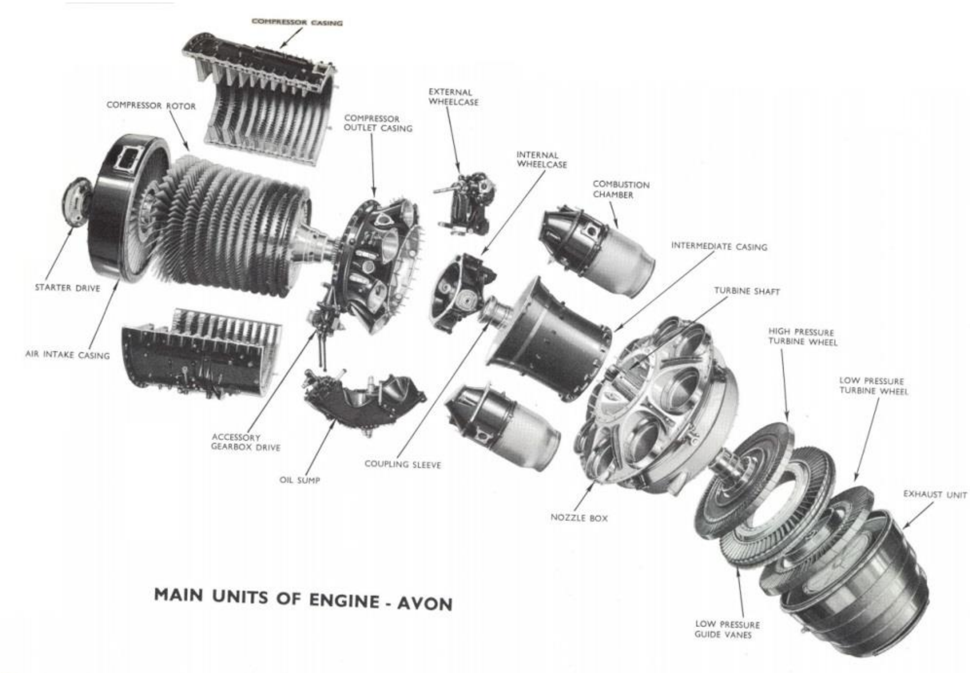
The Avon engine is a single shaft turbo jet engine comprising of a multi-stage axial flow compressor with variable inlet guide vanes. A multi-cannular combustion system provide heated airflow to a two stage axial flow turbine which drives the compressor and engine accessories via an internal gearbox and external mounted auxiliary gearbox.

The Avon engine was designed and manufactured by Rolls-Royce during the 1950's. As well as the Hawker Hunter the engine has been used in a variety of different military application by the UK MoD as well as overseas operators and covers a number of different mark numbers.

Several Avon powered Hunter aircraft are still flown by private operators, however these are not supported by Rolls-Royce.

The main engine units can be seen below.

Appendix E (Cont)



The engine did not detach from the airframe during the accident and remained installed. The airframe was held in the AAIB hanger facility which allowed a visual inspection of the intake and exhaust to be made. The air intake contained a large quantity of debris ingested during the accident. However it was possible to view a number of inlet guide vanes which appeared to be intact, (figure 1).

The engine's jet pipe had detached during the accident impact sequence which allowed the top section of the 2nd stage turbine blades to be seen. The blades that were visible were intact with no visual evidence of material loss. The lower section of the exhaust unit was distorted which restricted a complete view of the turbine (figure 2).

The engine was removed from the airframe by the AAIB to allow a detailed strip examination to be conducted. Rolls-Royce Air Safety Investigators were not present during the engine removal.

4.2 Engine Disassembly and Examination

The engine disassembly took place at the AAIB facility over the 8th/9th October 2015.

4.2.1 General engine appearance

The main engine casings and external surfaces were covered in a layer of soot / carbon (figure 3); this was considered to be the result of the post-crash fire. There was no evidence of any high energy disruption of the casings to support that the engine had suffered an uncontained mechanical break out.

With the engine removed from the airframe it was possible to see the amount of debris that had been ingested during the ground impact sequence. The front of the nose cone was detached allowing the starter motor to be viewed. This was also coated in soot however, the electrical connections were in place and intact (figure 4).

The exhaust unit was badly distorted over an area of approximately 180° (fig 5).

A visual assessment of the accessory units found that the external surface of each unit was soot blackened. The attached fuel pipework and electrical harnesses were in a distressed condition and commensurate with exposure to elevated temperatures. This along with the external blackening was considered to be the result of the post-accident fire

The disassembly commenced by removing the accessory units:

Dual Fuel Pump	s/n B359 LR
Acceleration Control Unit	s/n B36R
Taco Generator	s/n 30909/53
VIGV Ram	s/n WE 2863/R
Fuel Control Unit	p/n GP5857
Barometric Pressure Control Unit	s/n 489 LR
Fuel Differential Pressure Switch	s/n 390 LR

The Dual Fuel Pump, Acceleration Control Unit, Fuel Control Unit and Barometric Pressure Control Unit were returned to a repair facility for strip examination. The findings from the strip examination are detailed later in this report.

4.2.2 Air Intake Casing

The debris that had collected in the air intake had the appearance of a mixture of both organic and inorganic material. After the debris had been removed it was possible to view the intake guide vanes. All the vanes were present and those not covered by post-accident debris were coated in a layer of soot. Minor damage to the aerofoils was evident which was considered to be the result of debris ingestion. Due to a quantity of remaining debris it was not possible to establish if the vanes could be articulated. (fig 6).

4.2.3 Compressor Casing

The Avon compressor casing consists of two half casings joined by a line of bolts at mid-engine height. The bolts were removed and the top half casing lifted off to allow examination of the upper section of the compressor stator vanes. The vane set was complete and the majority were covered in a layer of soot. There was evidence of damage as a result of debris ingress but there was no visual evidence of pre-accident vane fracture (figure 7).

4.2.4 Compressor Rotor

Removal of the casing exposed the compressor rotor assembly which could be rotated. Occasionally the compressor rotation was difficult due to the presence of debris that had been ingested during the accident sequence.

A visual examination of the 12 stage compressor found all the blades to be intact, however, the majority displayed evidence of damage and material loss. All stages of blades were coated in a layer of loose carbon. Ingested debris was found as far rearward as stage 11 of the compressor. The location of the ingested debris and the nature of the damage to the compressor blades and vanes were consistent with the engine operating at the time of the accident. (figures 8 – 10).

The visual examination of the compressor found no evidence of pre-accident blade fracture.

4.2.5 Combustion Chambers

The Avon Mk122 has eight cannular combustion chambers. No evidence of external distress was found on the areas that were visible and all 8 combustion chambers were installed securely. Four were removed to facilitate a more detailed visual examination.

The four examined combustion chambers were intact with no evidence of external distress around the circumference. There was no visual evidence of distress on the internal surface and all four had a degree of carbon build up commensurate with normal operation, (figure 11).

4.2.6 Nozzle Box

The nozzle box was visually in a satisfactory condition. Evidence of metallic debris, resulting from compressor blade distress, was found around the combustion chamber location flange and the front of the HP guide vanes. This metallic debris most likely originated from the compressor aerofoils that were damaged by the ingested debris. It also indicates that the engine was operating at the time of the accident.

4.2.7 High Pressure Guide Vanes

Removal of four combustion chambers facilitated a visual examination of a number of HP guide vanes. The vanes were coated in a layer of carbon commensurate with engine operation. All the vanes viewed were intact and there was no visual evidence of any pre-accident distress (figure 12).

4.2.8 High Pressure (1st stage) Turbine

A visual assessment of the HP turbine blades found they were all intact with no evidence of pre-accident distress.

4.2.9 Low Pressure Guide Vanes

A visual assessment of the LP guide vanes found they were intact with no evidence of pre-accident distress.

4.2.10 Low Pressure (2nd stage) Turbine

The exhaust unit was removed allowing examination of the LP turbine disc and blades. All the blades were intact with no evidence of pre-accident distress or material loss, (figure 13). The disc was visually satisfactory and its condition was considered commensurate with the service life of the engine.

4.2.11 Exhaust Unit

The exhaust unit was severely distorted and commensurate with the accident sequence.

4.3 Accessory Unit Examination at the Repair Facility

The strip assessment of the accessory units was conducted at the UTAS repair facility. Unit disassembly was conducted by UTAS fitters and observed by personnel from the AAIB, Rolls-Royce Air Safety Investigation Department and Rolls-Royce Controls Engineers. The laboratory work was conducted at the Rolls-Royce Controls Laboratory.

4.3.1 Dual Fuel Pump - s/n B359 LR

The fuel inlet cover was removed whereby water and orange coloured contaminants were found inside the inlets, (figure 14), consistent with post-accident water ingress. The hydro mechanical governor cover was removed; the gasket was fitted correctly and in a good condition. The diaphragm assembly was removed and found to be visually clean and in good condition. The diaphragm and 'O' ring seal were also in a visually good condition.

The cross drive and HMG gears were removed to allow removal of each pump unit cover. The (fuel) carbon seal and (oil) shaft seal were visually in good condition. There was minor contamination and corrosion within the pump chambers consistent with post-accident water ingress.

The pump assemblies were removed where evidence of water contamination and corrosion were found, (figure 15). Tide markings show that this had occurred post-accident. There was slight erosion of the silver plate between the piston ports but the base material was not eroded. There was no evidence of cavitation and all the pistons moved freely in their ports.

The hydro mechanical governor was inspected and found to be in a visually good condition.

The pump diaphragm was examined by the laboratory. It is manufactured from two-plies of a Polychloroprene rubber proofed textile. The diaphragm consisted of two centrally located riveted plates with associated spring assembly. Around the plates is a shallow convoluted portion of the diaphragm which is exposed to aviation kerosene. The remainder of the diaphragm is compressed between surfaces acting as a gasket, (figure 16).

The laboratory assessment of the diaphragm found that the convoluted area on both sides had been significantly degraded. The rubber had the appearance of "Mud-Cracking" across the entire working surface. On one side of the diaphragm a "Tide-Mark" could clearly be seen across the convolution, (figure 17).

Mud cracking is a known condition that can occur if the diaphragm has had extended periods of non-operation while still immersed in kerosene. As the residual kerosene degrades, peroxides within the fuel can attack the rubber. The tide mark is an example of where fuel has drained away during periods of inactivity. A reduced exposure to kerosene will lessen the degrading effect of peroxides but will result in the diaphragm losing flexibility resulting in the observed mud cracking as the fuel no longer acts as a plasticiser for the rubber.

Nevertheless, the diaphragm was still integral and its functional capability had not been compromised. It is also worthy of note that the design of governor installed on this standard of dual fuel pump will govern at a higher engine speed if the diaphragm ruptures. However, in its current condition its integrity for continued use has been brought into question.

4.3.2 Fuel Control Unit - p/n GP5857

Prior to returning the FCU to the OEM the main fuel filter was removed and visually examined. There was no visual evidence of debris found within the filter element.

The throttle valve housing end cover was removed which found that the valve plunger was clean and moved freely during actuation of the input lever.

Removal of the throttle valve housing found the metering port to be clean and in good condition. The metering end of the plunger was also clean and in good condition, (figure 18). The housing 'O' ring was fitted correctly and visually in good condition.

The throttle valve input lever and shaft were removed which found the gasket to be fitted correctly and in a visually good condition. Light damage marks were noted on the rack teeth. This was most likely caused during assembly, but did not affect the operation of the throttle valve.

The metering plunger was removed from the housing and found to be in a visually good condition as was the metering housing bore, (figure 19).

Removal of the pressurising valve housing found that all the internal components were correctly assembled and in a visually good condition.

The HP cock housing assembly was removed from the main body to allow a visual examination of the valve operation. The valve was free to move over its full range and there was no evidence of play in the assembly, (figures 20 & 21). All the fuel washed surfaces that could be inspected were found to be visually clean and in good condition.

4.3.3 Acceleration Control Unit - s/n B36R

The bellows cover was removed which revealed the bellows and housing to be visually clean and in good condition. The damping oil present in the unit was clean with no visual evidence of contamination.

Removal of the spring cover found the two 'O' ring seals correctly seated and in good condition. The housing and spring assembly were clean and visually in good condition.

The servo line filter and orifice housing were removed, the orifice hole had evidence of erosion between the hole and end face corner. The half ball valve had what appeared to be fine pitting in line with the orifice and there were small amounts of debris identified in the servo line filter.

All components within the adjuster housing were clean and visually in a good condition, (figure 22). The diaphragm separating bleed valve pressure and compressor delivery pressure was visually in a good condition as was the diaphragm between the compressor delivery pressure and bellows chamber. The compressor delivery pressure chamber was visually clean and in a good condition.

The pressure balance lever was in a good condition but with a small quantity of a black deposit noted around the needle roller support point. This was not considered to be detrimental to the operation of the unit, (figure 23).

The two ACU diaphragms were submitted to the laboratory for examination. None of the rubber surfaces exhibited evidence of aging, i.e. cracking or splitting, however, there was some evidence of compression set on the beaded section of the smaller diaphragm.

Both diaphragms operate in air and so were not affected by degrading kerosene and were considered to be in a satisfactory condition.

4.3.4 Barometric Pressure Control Unit - s/n 489 LR

On removal of the bellows chamber cover the sealing gasket was found to be in a good condition. The damping oil in the bellows chamber was clean and the bellows were in a good condition, (figure 24). Manipulation of the bellows assembly at its centre locating feature found the vacuum was still functional.

The ACU adjusting housing was removed, the gasket and all internal components were in a visually good and clean condition, (figure 25).

The pressure tapping housing was removed, its gasket was in a good condition. The diaphragm and piston were also in a visually good condition as was the pivot point assembly

The BPC diaphragm was examined by the laboratory. It is manufactured from Nitrile rubber and has an inherent resistance to kerosene. Its removal from a kerosene environment has not had a detrimental effect on its condition. The rubber hardness was assessed and found to be 73 IRHD which was deemed acceptable for this type of material.

The BPC unit also has an 'o' ring seal and a seal consisting of a small Nitrile disc with a beaded edge. The 'O' ring seal had some degree of compression set which was also evident in the beaded section of the disc seal but the hardness values of both seals was acceptable. The 'O' ring seal did not exhibit evidence of degradation or aging.

4.4 Engine Performance Assessment.

Rolls-Royce was tasked to carry out a performance assessment to establish whether or not the engine was performing as expected leading up to and just prior to the accident.

To assist the AAIB in their investigation Rolls-Royce were also asked to establish a set of engine performance parameters that could be used with a different mark of Avon engine (Mk207) in flight trials. These parameters were:

1. The rpm for a Mk207 to give the equivalent thrust to a Mk122 at full throttle (8150 rpm)
2. The rpm for a Mk207 to give the equivalent thrust to a Mk122 whilst performing the final airshow manoeuvre.

To conduct the assessment Rolls-Royce was provided with engine speed (rpm) and Jet Pipe Temperature (JPT) from the airshow flight. Jet Pipe Temperature was taken from snapshots of the cockpit gauge via a recording from a camera situated in the cockpit. Engine rpm was obtained from frequency (spectrographic) analysis of the cockpit noise recording. This data was supplied by the AAIB following an assessment which found a good correlation between the two parameters and expected values.

The Performance Brochure for the Mk122 obtained from a Rolls-Royce archive contained a chart which detailed jet pipe temperature, thrust and specific fuel consumption against engine rpm for ISA, SLS conditions (i.e. standard day conditions of 15̊C and 14.696psi). The relationships between JPT and rpm, and thrust and rpm, used in this analysis have been taken from this data.

Performance and configuration data for Rolls-Royce engines as of August 1983; state that for the Mk207 the minimum thrust at sea level is 9950lb at 8000rpm.

To perform the required analysis for the Mk207, a performance definition was required. There was no performance model of the Mk207; however, there was a performance model for a higher rated Avon Mk200 series engine. This model was created in 2004 and was considered the most likely to represent the Mk207 minimum thrust at sea level of 9950lb at 8000rpm. Therefore, a thrust versus speed relationship was derived for the Mk207 by interpolating between the higher rated Mk200 and the lower rated Mk122, based on the ratio of thrusts between the three marks at 8000rpm. The interpolated Mk207 performance characteristics have therefore been used in the subsequent analysis.

In order to carry out the analysis a standard assumption used commonly in engine performance analyses has been utilised. This assumes that engines behave non-dimensionally when operating between choked nozzles, for a fixed engine geometry.

It is possible to define, for each common performance parameter (thrust, engine speed, pressure, temperature and mass flow), a full non-dimensional version and a more commonly used semi-dimensional version that allows performance parameters to be compared at different flight conditions. Dimensional parameters plotted at different flight conditions will combine onto the same line if plotted non-dimensionally, figure 26. Equally, non-dimensional corrections can be used to establish engine performance at other flight conditions for a given input.

It should be noted that brochure performance such as that used here is stated at uninstalled, steady state conditions (i.e. stable and well thermally soaked) and for a new engine. Variations such as airframe architecture, including power off-takes and air bleeds and allowing for intake losses, engine deterioration and non-stabilised conditions, will all affect the relationship. Therefore it has not been possible to quantify the effects of these uncertainties in the analysis due to the lack of available data.

To assess the performance of the engine during the accident sortie the analysis was carried out at two spot points. The points chosen were taken when the engine was operating at a relatively stable condition. This aligns with the performance brochure data which is quoted at steady state condition. JPT was the parameter used as this is a good indicator of engine health and performance.

The analysis results show a good alignment between the Mk122 brochure derived JPT and the JPT retrieved from the airshow data. This gave a level of confidence that the engine was performing largely as expected and that no major performance changes had taken place. The results are within expectation given the uncertainty around engine installation, stabilisation and deterioration. However, it has not been possible to combine the engine parameters obtained from the airshow flight with the throttle lever position, therefore it cannot be determined if the level of thrust delivered by the engine matched that demanded by the pilot.

The analysis to establish the rpm required for a Mk207 to give the equivalent thrust to a Mk122 at full throttle (8150 rpm) gave an average target mechanical speed of approximately 7400rpm. However, this result has a number of caveats associated with it. These include:

a) The Mk207 characteristic used is a derived characteristic based on a crude interpolation from two other Avon marks.
b) Effects such as stabilisation, engine installation and engine deterioration will affect the thrust versus speed relationship for each engine. The analysis assumes each engine is developing thrust in line with the brochure or derived characteristic.
c) No account is taken for any differences in airframe configuration which may affect aerodynamic performance.
d) Potential operability issues associated with operation at part power, e.g. blow-off valve operation, have not been assessed.

The third analysis was to establish the rpm for a Mk207 to give the equivalent thrust to a Mk122 whilst performing the final airshow manoeuvres. Flight conditions for this assessment have been extracted from the originally supplied data.

Three manoeuvres were considered, these were the initial pull up, the rpm reduction between pull up and inverted flight and while inverted. Five different flight conditions were also used at each of these manoeuvres to take into account uncertainty in determining the exact flight condition. Additional flight conditions of 1000ft and 3000ft, each at ISA-5 and ISA-10 were also used to give a range of 20 different Mk207 engine speeds. These are shown in figure 27.

The resultant engine speeds required at each of the airshow manoeuvre points and for each of the flight test points show very little difference. These have been plotted alongside the engine speeds observed during the airshow and can be seen in the figure 28.

5 CONCLUSION

- Strip examination of the engine found that its condition was commensurate with its age with no evidence of pre-accident anomalies.

- Debris found within the core of the engine was consistent with the engine operating at the point of impact.

- Detailed strip examination of the accessory units found nothing that would prevent the engine from operating across its full speed range.

- Laboratory examination of the seals and diaphragms from the accessory units found that some had evidence of age degradation. However, there was no evidence that seal or diaphragm integrity had been compromised or that they would have prevented the engine from operating normally.

- A comparison of the engine speed obtained via spectral analysis in conjunction with video evidence of engine operating temperatures has found that the engine appeared to be operating in a stable manner throughout the incident flight.
- A performance assessment has found that the engine was performing largely as expected and that no major performance changes had taken place.
- Throttle lever position during the accident flight could not be determined therefore it has not been possible to establish if the level of thrust delivered by the engine matched that demanded by the pilot.

6 SIGNATURES

REPORT COMPILED BY

Signed [redacted] Date [redacted]

COMMENTS OF CHIEF ENGINEER - PEGASUS, HELICOPTERS AND TRANSPORT

[redacted]

Signed [redacted] Date [redacted]

REPORT APPROVED BY MANAGER – AIR SAFETY INVESTIGATION

Nothing in this report shall be, or be deemed to be, an admission by the Company of any liability whatsoever, howsoever arising in respect of any loss, damage, death or injury.

Signed [redacted] Date [redacted]

7 FIGURES

Figure1: A view looking at the front of the engine while installed

Figure 2: A section of the 2nd stage (LP) turbine viewed through the distorted exhaust unit.

Appendix E (Cont)

Figure 3: A view of the left side of the engine after removal from the airframe. Although the front half is coated in a layer of soot from the post-accident fire, the engine is complete.

Figure 4: A view looking at the front of the engine. The level of ingested post-accident debris is clearly visible.

Appendix E (Cont)

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Figure 5: This is a view of the rear of the engine showing the distorted exhaust unit.

Figure 6: A closer view of the variable inlet guide vanes. The majority of debris has been removed at this stage.

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Appendix E (Cont)

Figure 7: The top section of the compressor half casing. All the stator vanes are present but are coated in a layer of post-accident fire soot.

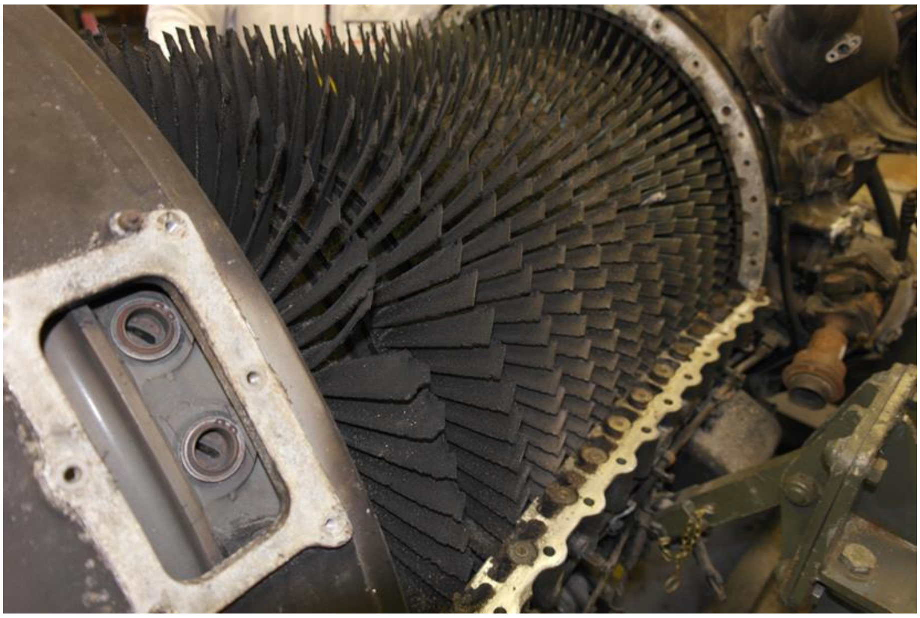

Figure 8: A general view of the compressor. Blade distress is clearly visible and the post-accident fire sooting is clearly visible.

Appendix E (Cont)

Figure 9: a close up view of the mid-stages of the compressor. Damage to the leading and trailing edges of all the blades can be seen.

Figure 10: A piece of ingested debris was found within the stage 11 blades, (arrowed)

Figure 11: A general view inside one of the combustion chambers. All the inspected chambers were similar and considered satisfactory.

Figure 12: A section of HP guide vanes viewed through the nozzle box.

Appendix E (Cont)

Figure 13: A general view of the 2nd stage (LP) turbine. All the blades were present and the general condition of the turbine was considered satisfactory.

Figure 14: A general view of the dual fuel pump after removal of the fuel inlet cover. The orange coloured liquid is the result of post-accident water ingress.

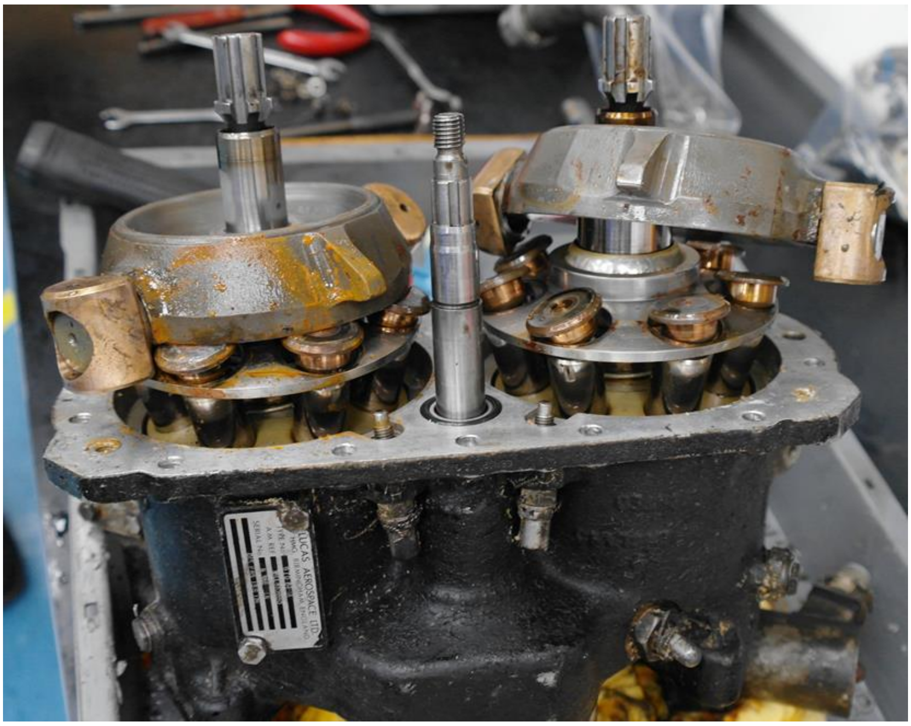

Figure 15: The condition of the pistons within each pump was satisfactory. The post-accident water damage is also evident.

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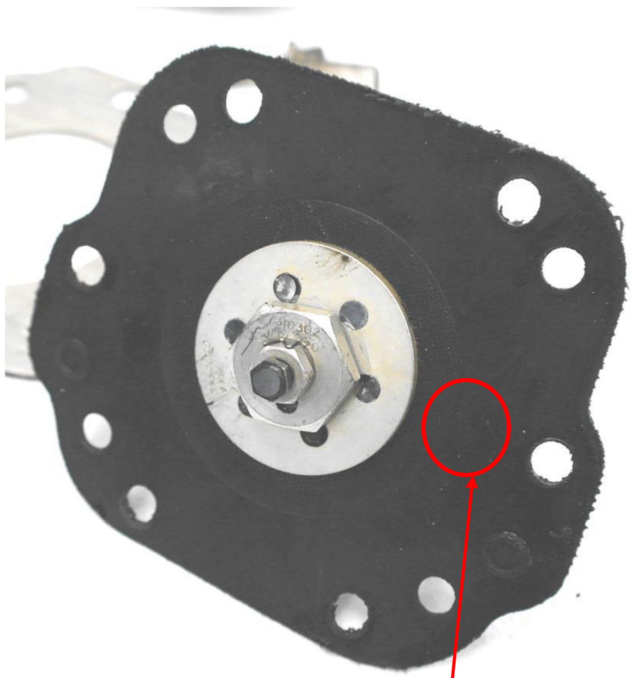

Figure 16: a general view of the dual fuel pump diaphragm.

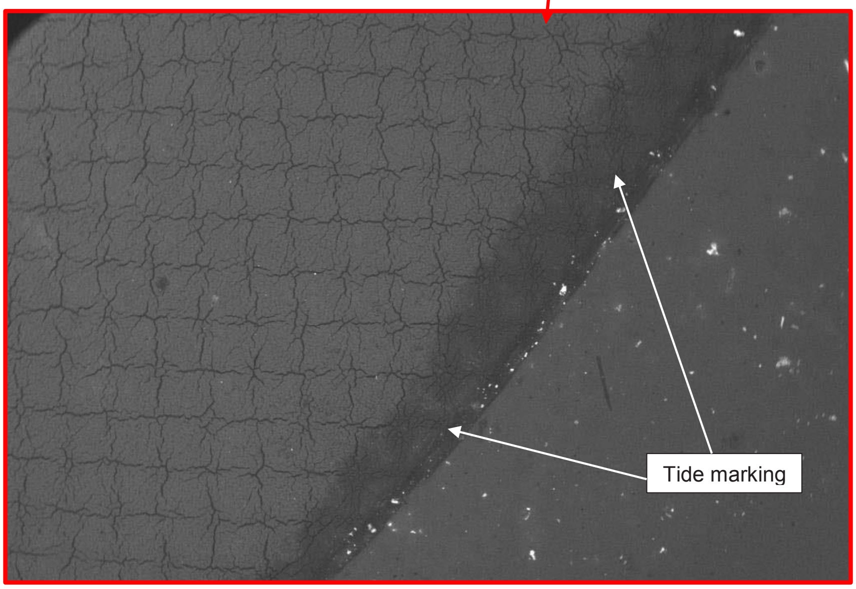

Figure 17: A close up view of the ‘mud cracking’ and tide marking seen in the convoluted section.

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Appendix E (Cont)

Security classification
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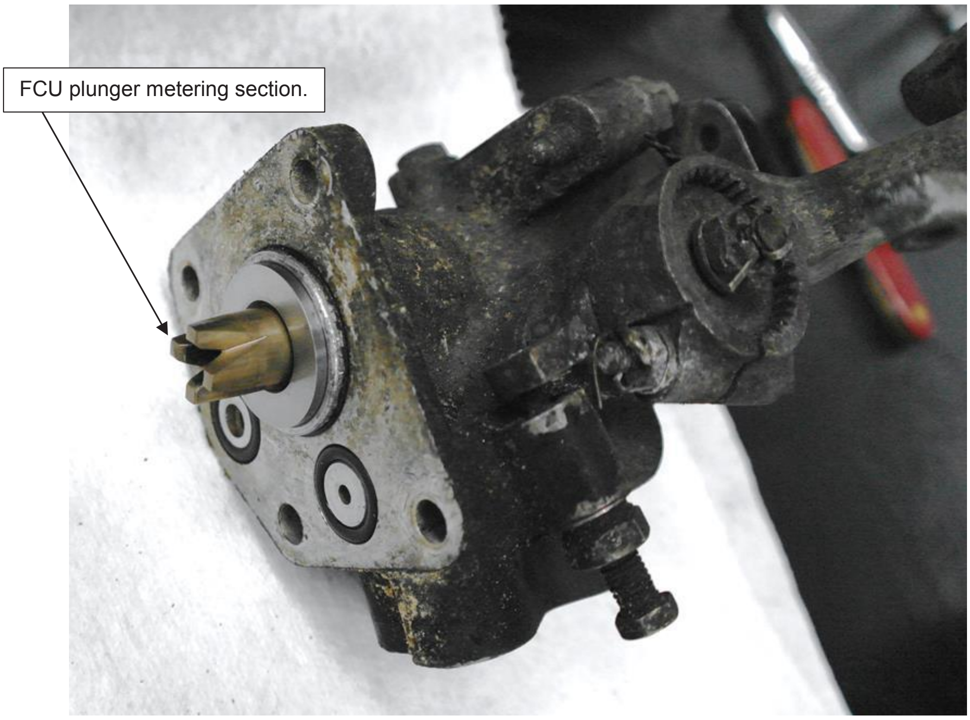

Figure 18: The metering section of the FCU plunger was clean and in a satisfactory condition.

Figure 19: After removal of the metering plunger its general condition was considered to be satisfactory

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Appendix E (Cont)

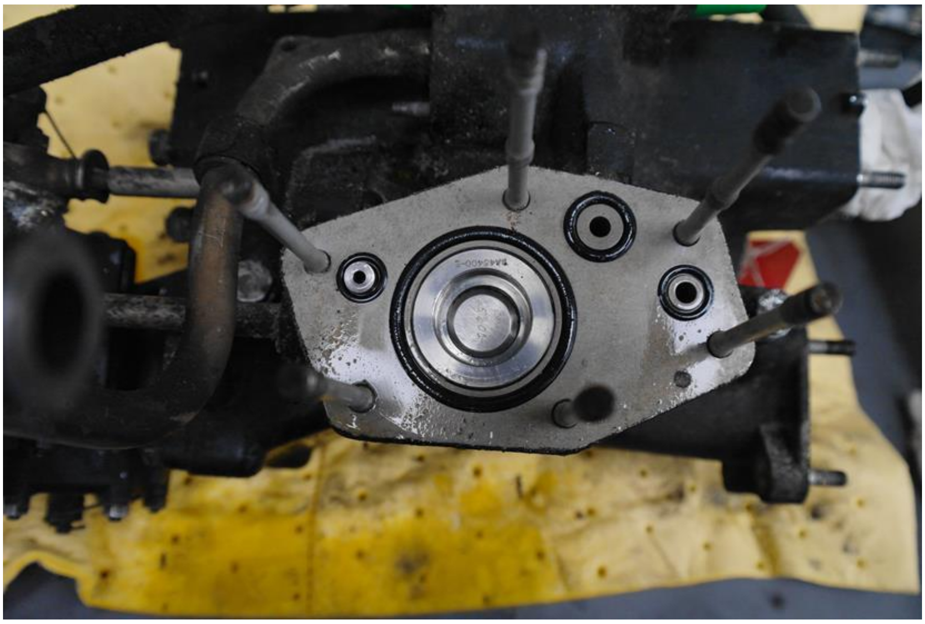

Figure 20: One half of the HP shut off cock housing. The internal components were clean and the 'O' ring seals were in a good condition.

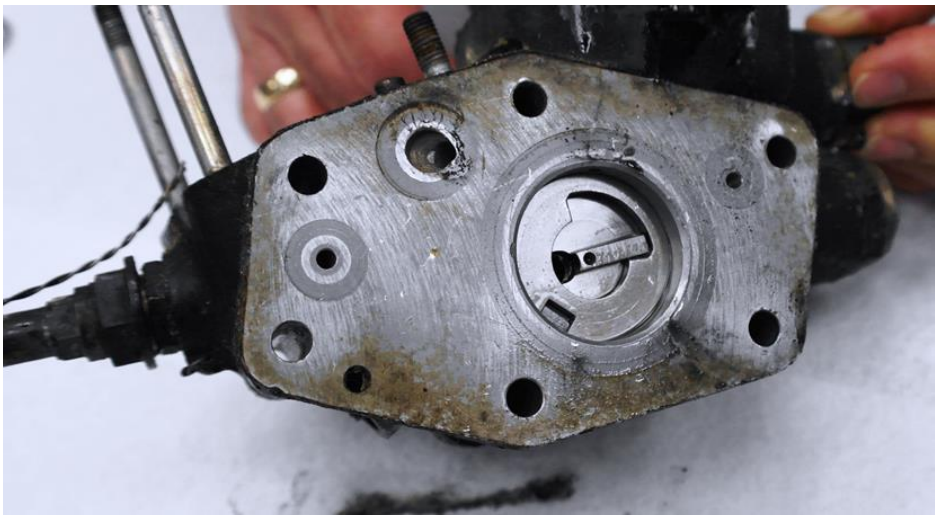

Figure 21: This is the opposite half of the shut off cock seen in figure 19. The valve was clean and its operation was smooth and unrestricted.

Appendix E (Cont)

Security classification
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Figure 22: A general view of the bellows assembly and components from the adjuster housing within the ACU

Figure 23: The pressure balance lever for the ACU which was considered to be in a good visual condition. The black deposit noted during the strip can be seen close to the needle roller contact point.

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Appendix E (Cont)

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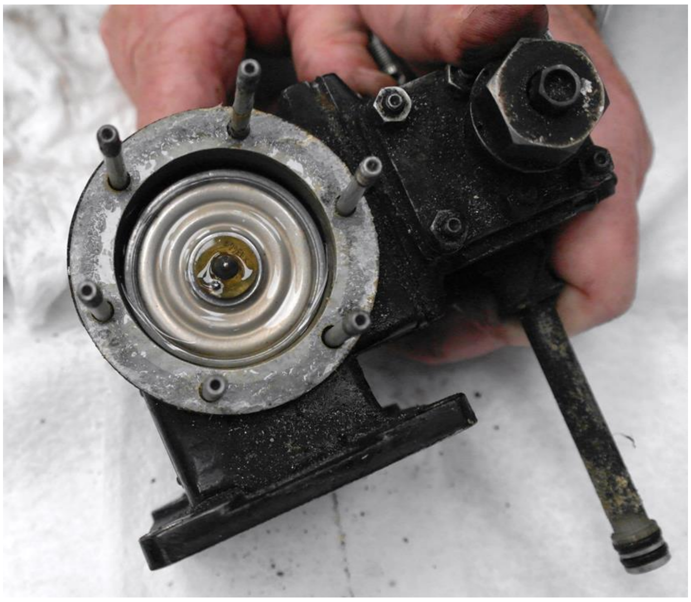

Figure 24: The bellows assembly of the BPC while installed. The damping oil around the bellows was clean with no visual evidence of contamination.

Figure 25: Another view showing the clean condition of the BPC adjustment housing.

Document number EFI/1186	Issue 1	Security classification Private – Rolls-Royce Data	Page 24 of 26

Appendix E (Cont)

Security classification
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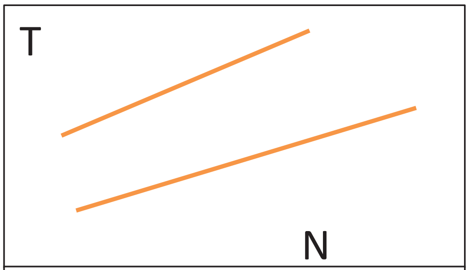
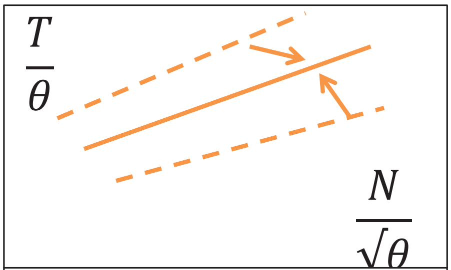


Engine temperature versus engine speed at two different flight conditions



Same data plotted non-dimensionally: Non-dimensional engine temperature versus non-dimensional engine speed collapse onto same line

Figure 26: Graphs showing the use of non-dimensional values.

<table>
<tr><th>Manoeuvre</th><th>Flight Condition</th><th colspan="4">Starting Altitude and OAT for each Flight Condition</th></tr>
<tr><td>Start of pull-up</td><td>1000ft 300KIAS</td><td rowspan="5">1000ft
ISA-5</td><td rowspan="5">1000ft
ISA-10</td><td rowspan="5">3000ft
ISA-5</td><td rowspan="5">3000ft
ISA-10</td></tr>
<tr><td>Mid pull-up 1</td><td>1800ft 240KIAS</td></tr>
<tr><td>Mid pull-up 2</td><td>2200ft 200KIAS</td></tr>
<tr><td>Inverted 1</td><td>3400ft 100KIAS</td></tr>
<tr><td>Inverted 2</td><td>4400ft 100KIAS</td></tr>
</table>

Figure 27: This details the 20 different flight conditions used to determine the equivalent Mk207 engine speeds.

Appendix E (Cont)

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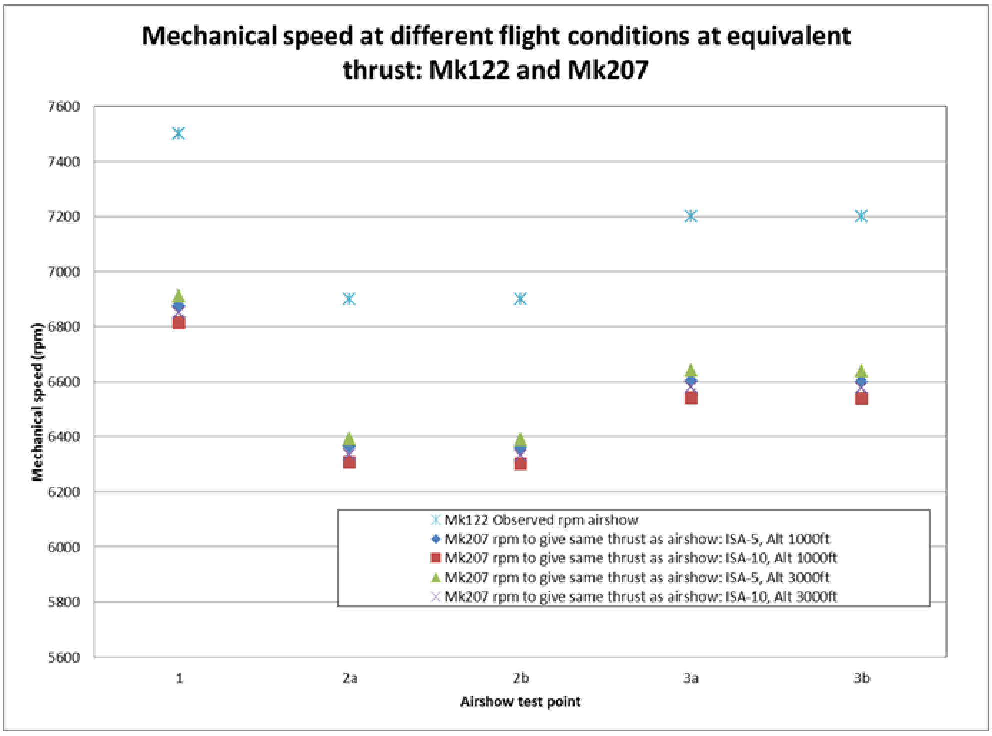

Figure 28: Engine mechanical speed and thrust comparison fixed flight conditions.

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Appendices

Appendix F

Laboratory Report of ACU, BPC and Hydro-mechanical Governor Diaphragms

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EXTERNAL CIRCULATION AUTHORISATION AND EXPORT CONTROL (Ref. ES 32-206) MER reports MUST NOT be circulated outside Rolls-Royce Controls without first obtaining the permission and signature of the Manager of the Project/Function for the subject of this report and then countersigned by the Lead Materials Engineer.

TAS Code	Department	Date
AD018-800-010-000-403	Product Support	[redacted]

Part No	Description	Customer	
-	Fabric reinforced diaphragms	[redacted]	
Material Type	**Material Specification**	**Unit Type**	**Serial No**
Textile Reinforced Polychloroprene Nitrile Rubber	-	GTD64-1A / ACU / GP10055A / BPC 19-24U	-
ID Ref	**Supplier**	**Engine**	**Running Time**
-	-	[redacted]	-

Reason for Submission and Additional Information
The condition of the diaphragms is required to ascertain their performance integrity.

Circulation		
[redacted]		
[redacted]		

Export Control Requirements		Document Classification
Function Manager		**Date**
Lead Materials Engineer		**Date**

[redacted]

[redacted]

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1.0 SCOPE OF WORK

One solid rubber diaphragm, three fabric-reinforced diaphragms and associated rubber items were submitted for evaluation. All of the components were visually examined, measured for rubber hardness where possible; material identification using Infra-Red spectroscopy. The pump diaphragm was also examined using a Scanning Electron Microscope.

2.0 OBSERVATIONS

2.1 Diaphragms

2.1.1 Pump – Operating in Aviation Kerosene

2.1.1.1 The diaphragm consisted of two centrally located riveted plates with associated spring assembly. Around the plates was a shallow convoluted portion of the diaphragm which had been exposed to aviation Kerosene. The remainder of the diaphragm had been compressed between surfaces acting as a gasket. Both sides of the diaphragm are shown in general view by figures 1 and 2.

2.1.1.2 The diaphragm had not perforated.

2.1.1.3 The convoluted area on both sides had been significantly degraded and the rubber had been now “Mud-Cracked” across the entire working surface.

2.1.1.4 On one side of the diaphragm a “Tide-Mark” could clearly be seen across the convolution, see figure-3.

2.1.1.5 The area associated with the “Tide-Mark” appeared to have a greater degree of “Mud-cracking” of the rubber coating.

2.1.1.6 “Mud-cracking” was at its worst in the area adjacent to the spring retaining plates, where the diaphragm is subject to the most movement when in operation, see figures-3 and 4.

2.1.1.7 To image the “Mud-cracking” more clearly the diaphragm was viewed using a Scanning Electron Microscope,(SEM) using the “Variable Pressure” Mode to avoid charging of the diaphragm, see figures-4 to 9 for Face 1 and Figures-10 to 11 for Face 2.

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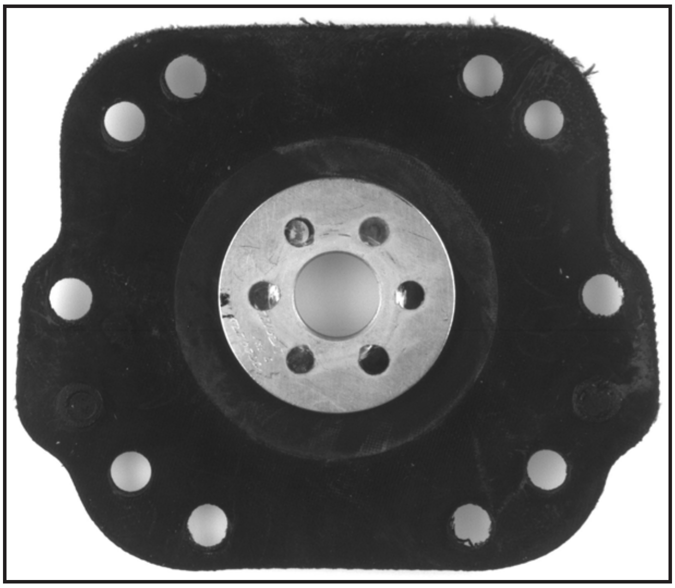

Figure 1 [redacted] GD64-1A Pump Diaphragm (Face-1)

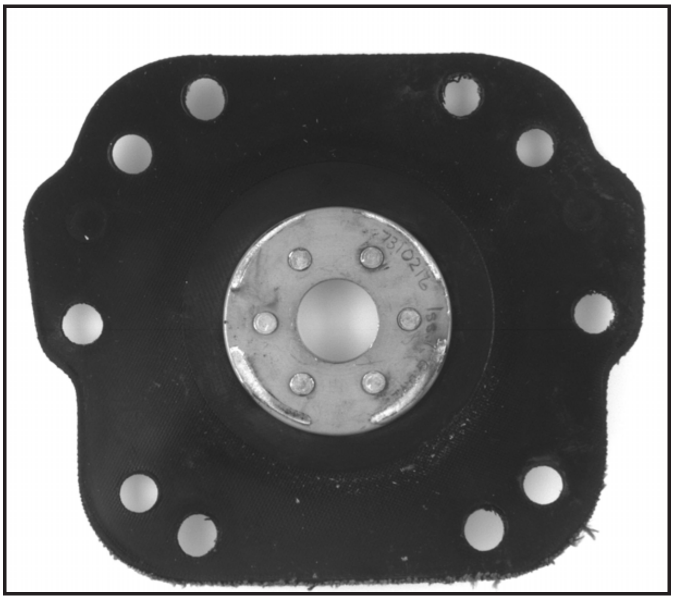

Figure 2 [redacted] GD64-1A Pump Diaphragm (Face-2)

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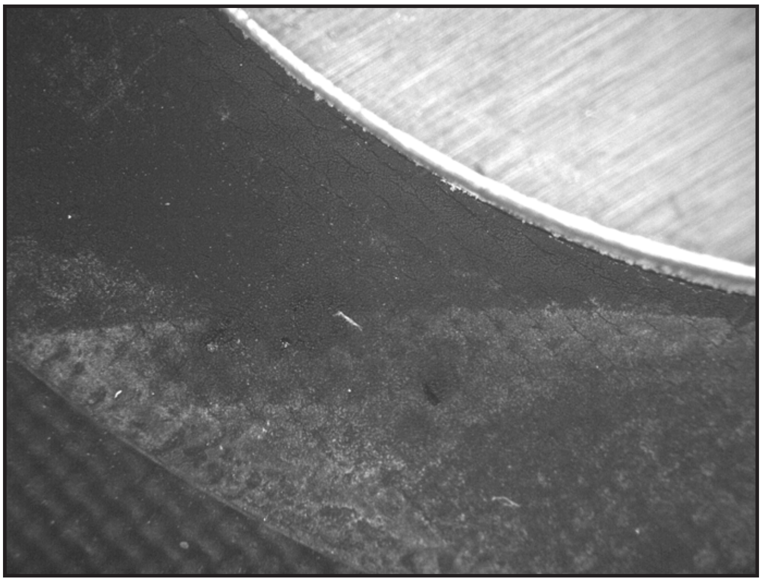

Figure 3 [redacted] GD64-1A Pump Diaphragm Tide Mark (Face-1)

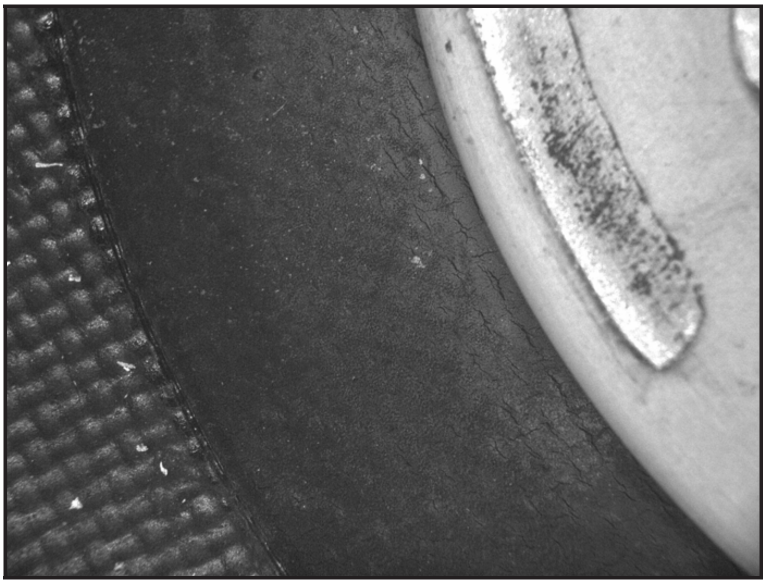

Figure 4 [redacted] GD64-1A Pump Diaphragm Cracking (Face 2)

Appendix F (Cont)

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2.1.1.8 The SEM images of Face-1 show the "Mud-Cracking" was present over the entire surface of the convolution.

2.1.1.9 The contrast between the "Mud-Cracked" convolution, in the "Tide-Mark" and protected clamped area is shown by figure-5.

2.1.1.10 The slightly lesser degree of "Mud-Cracking" of the convolution, not associated with the tide mark, is shown by figure-6.

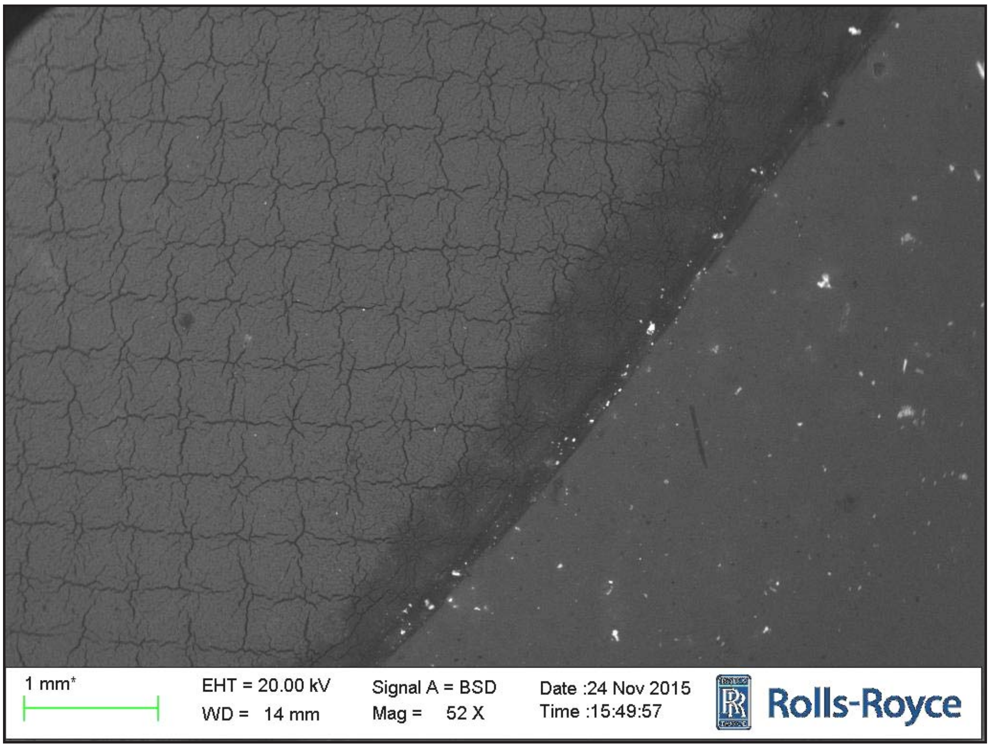

Figure 5 [redacted] GD64-1A Pump Diaphragm "Tide Mark" Region (Face 1)

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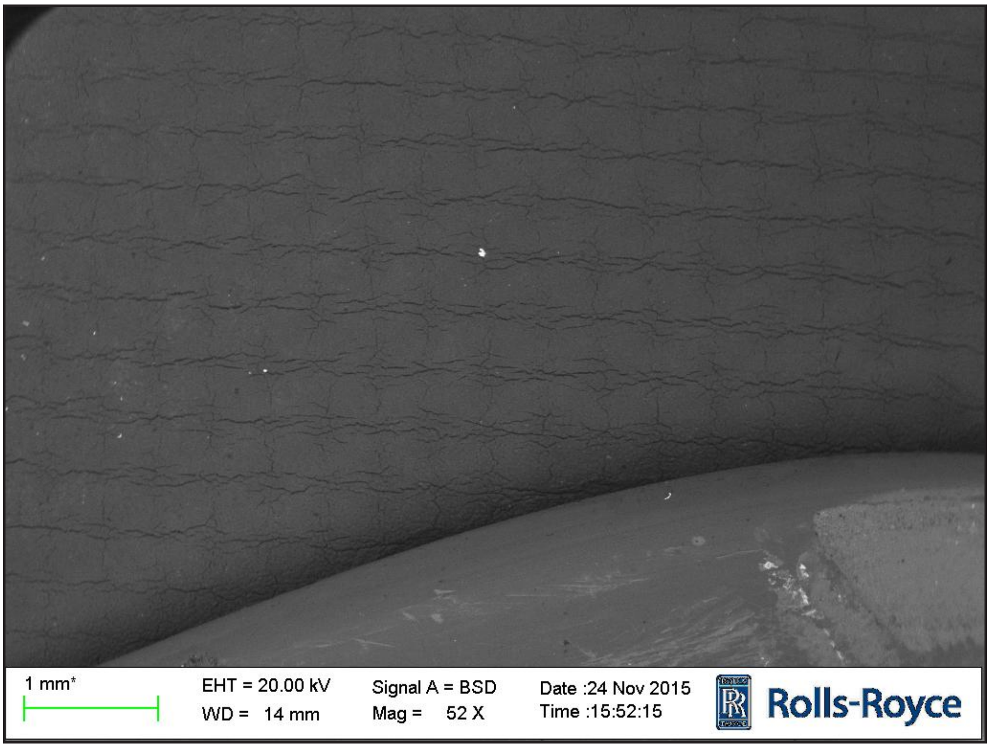

Figure 6 [redacted] **GD64-1A Pump Diaphragm General Convolution (Face 1)**

2.1.1.11 A severely "Mud-Cracked" region is shown by figure-7 and a high magnification close-up by figure-8.

2.1.1.12 The "Mud-Cracked" surface of Face -2 is shown by Figures-9 and 10.

2.1.1.13 The "Mud-Cracking" on Face 2 appeared to have a degree of directionality.

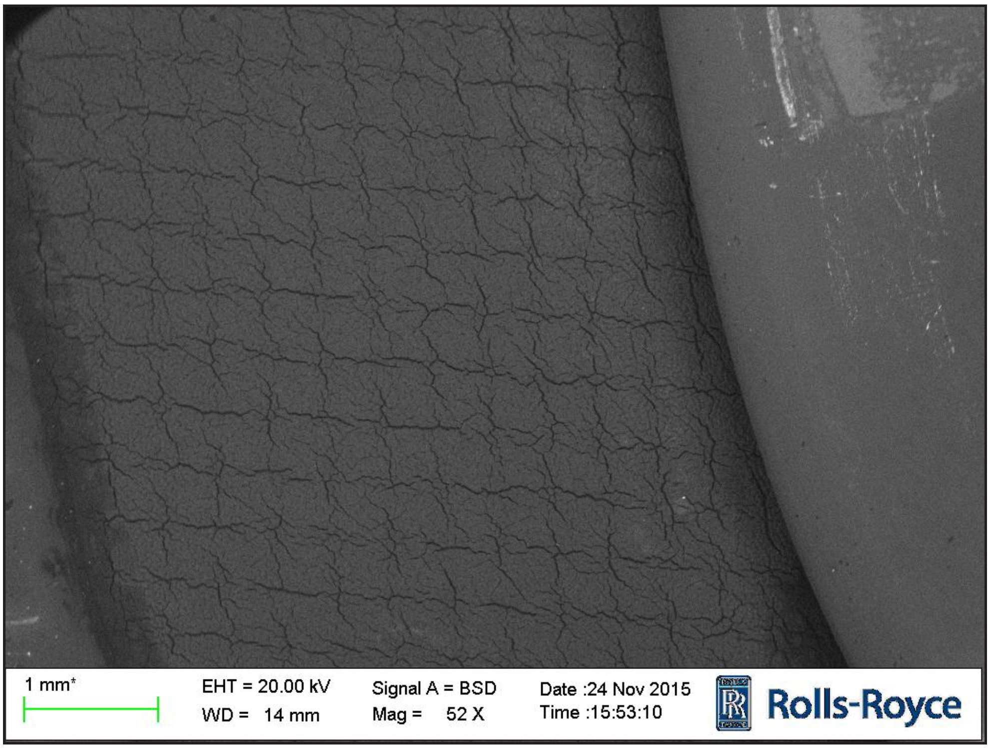

Figure 7 [redacted] **GD64-1A Pump Diaphragm Convolution (Face 1)**

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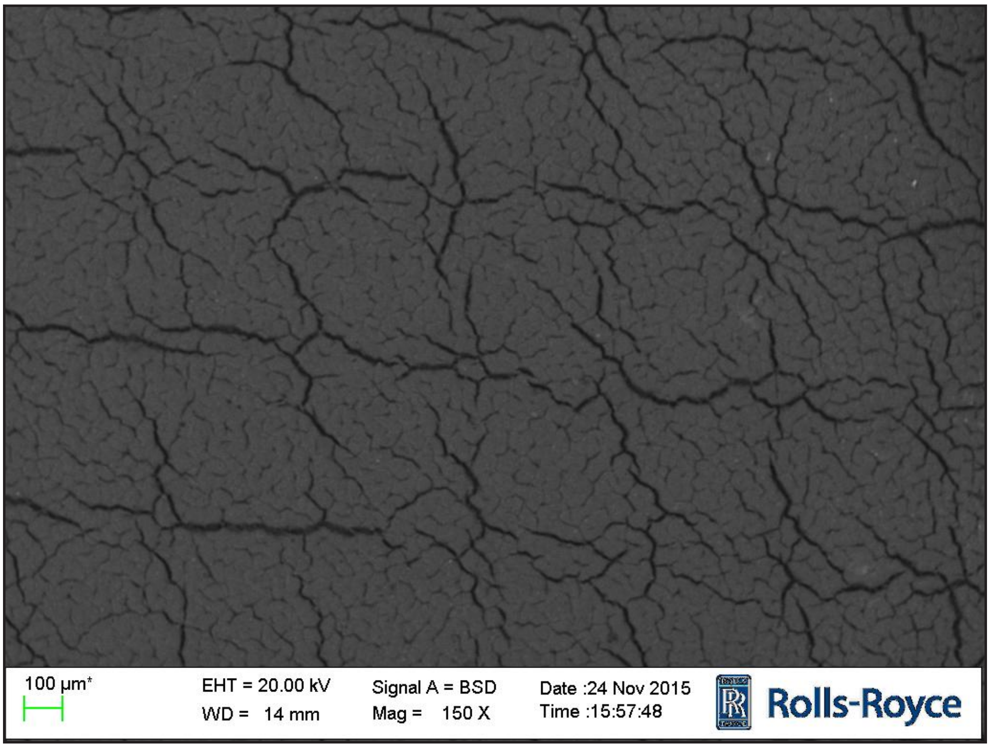

Figure 8 [redacted] GD64-1A Pump Diaphragm Convolution (Face 1)

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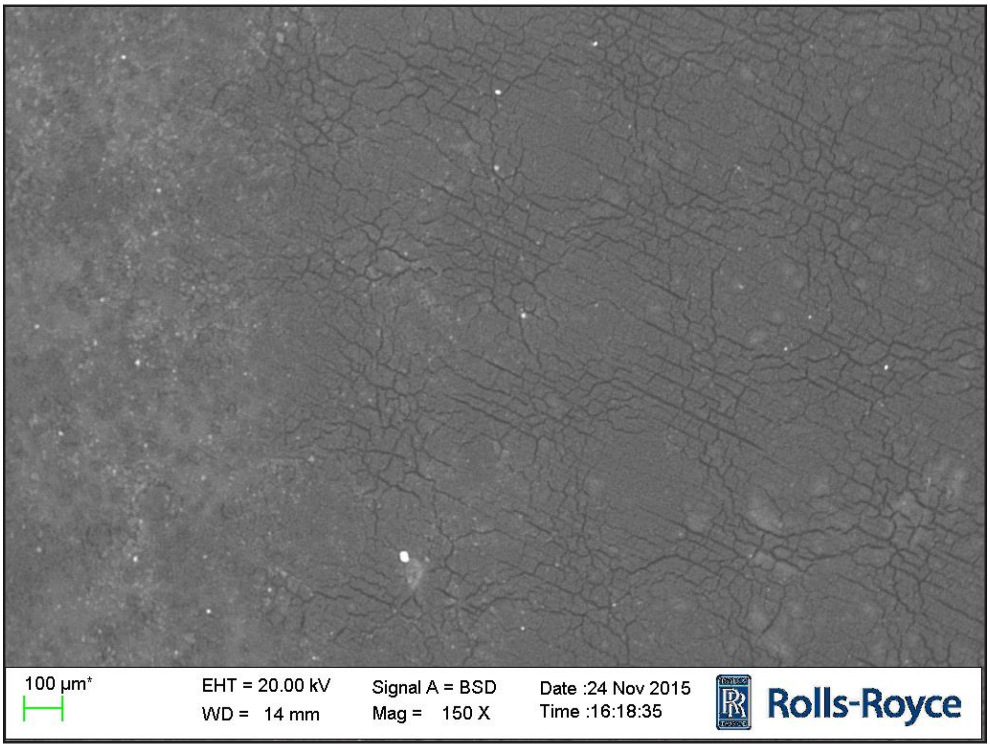

Figure 9 [redacted] GD64-1A Pump Diaphragm Convolution (Face 2)

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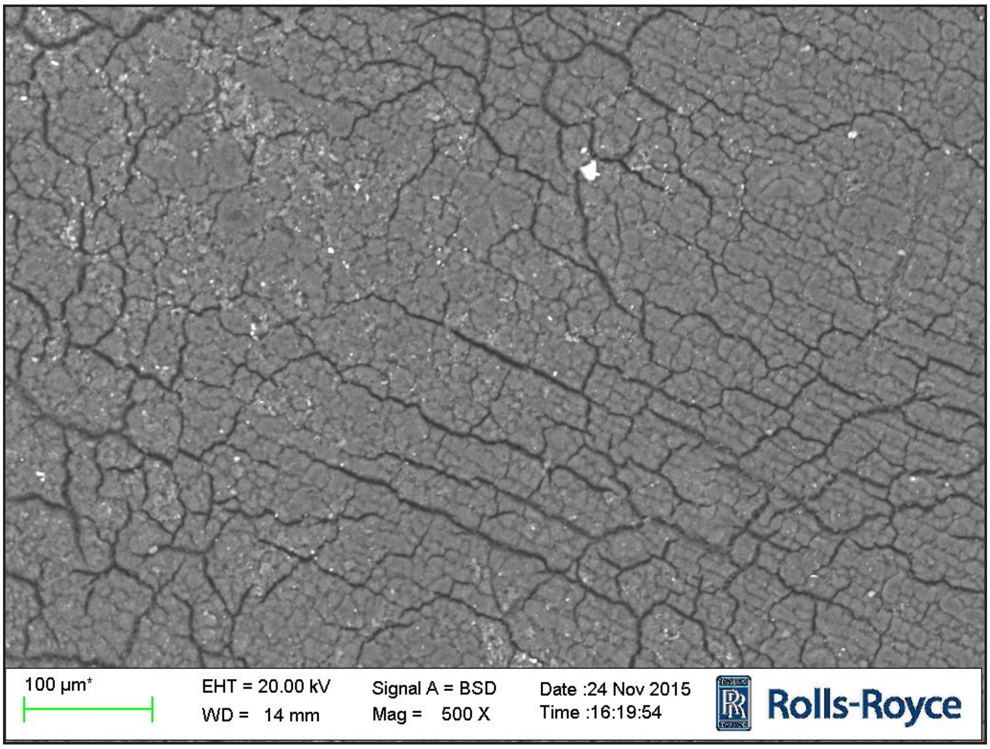

Figure 10 [redacted] GD64-1A Pump Diaphragm Convolution (Face 2)

2.1.2 Acceleration Control Unit (ACU) – Operating in Air (x2)

2.1.3 The smaller diameter (~38.5mm) of the two diaphragms consisted of a beaded diaphragm moulded to central anodised aluminium plates. The diaphragm appeared to be a single ply of textile proofed with a Polychloroprene rubber, see figures-11 and 12.

2.1.4 None of the rubber surfaces, convolution or clamped area, exhibited evidence of aging, *i.e. cracks, splits or rubber reversion. See figures 13 and 14.*

2.1.5 The beaded portion of the diaphragm had taken a permanent compression set, having presumably originally been "O-shaped", see figure-15.

2.1.6 On the high pressure face there was some evidence of loss of adhesion between the rubber and the metal plates see figure-16.

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2.1.7 The larger diameter diaphragm, (~63mm) consisted of two plies of a Polychloroprene rubber proofed textile.

2.1.8 None of the rubber surfaces, convolution or clamped area, exhibited evidence of aging, *i.e. cracks, splits or rubber reversion. See figures-17 to 20.*

2.1.9 The rubber to metal bonding was in good condition with no evidence of delamination or loss of adhesion to the metal plates.

2.2 Barometric Pressure Control – Operating in Aviation Kerosene (Solid Rubber Diaphragm)

2.2.1 This diaphragm was manufactured from a Nitrile Rubber which has inherent resistance to aviation fuel.

2.2.2 Removal from fuel had not had a detrimental effect upon the diaphragm, see figure-21.

2.2.3 The rubber hardness of 73 IRHD was an acceptable value for a rubber material of this type and for the application.

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Figure 11 Acceleration Control Unit Diaphragm (Small) Face-1

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Figure 12 Acceleration Control Unit Diaphragm (Small) Face-2

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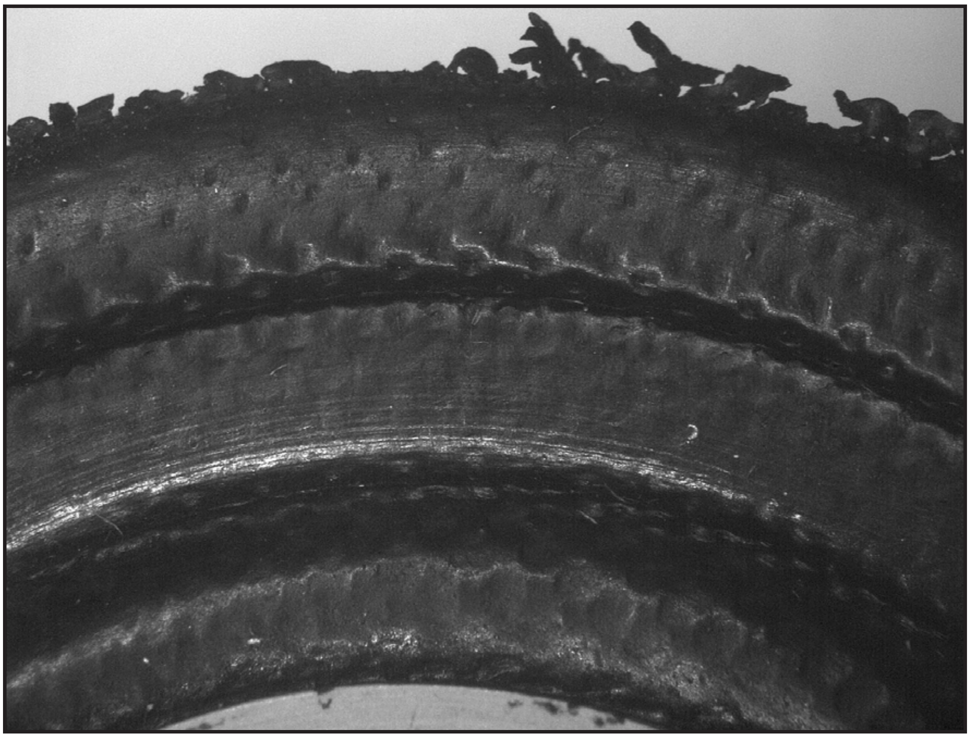

Figure 13 Acceleration Control Unit Diaphragm (Small) Face-1

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Figure 14 Acceleration Control Unit Diaphragm (Small) Face-2

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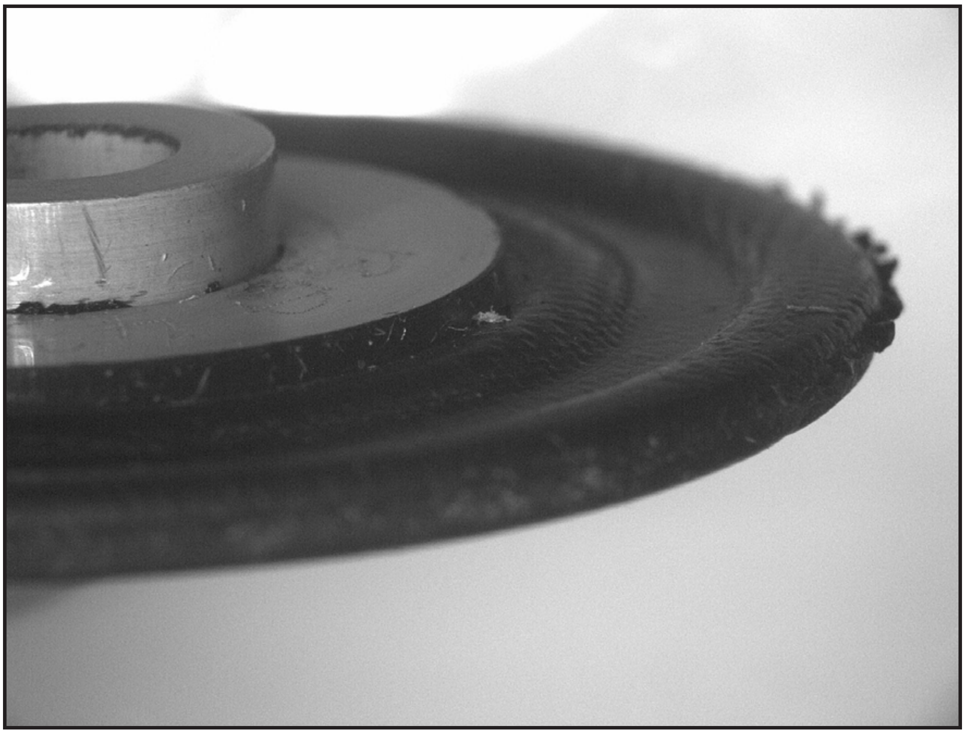

Figure 15 Acceleration Control Unit Diaphragm – Bead Compression Set

Appendix F (Cont)

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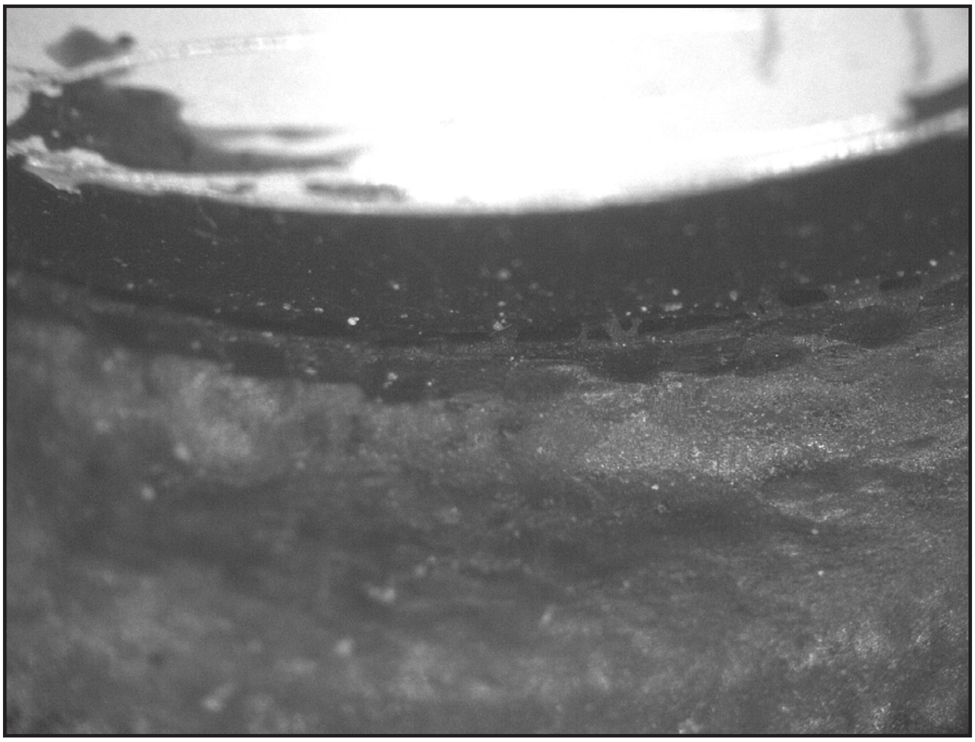

Figure 16 Acceleration Control Unit Diaphragm – Adhesion Loss

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Figure 17 Acceleration Control Unit Diaphragm (Large) Face-1

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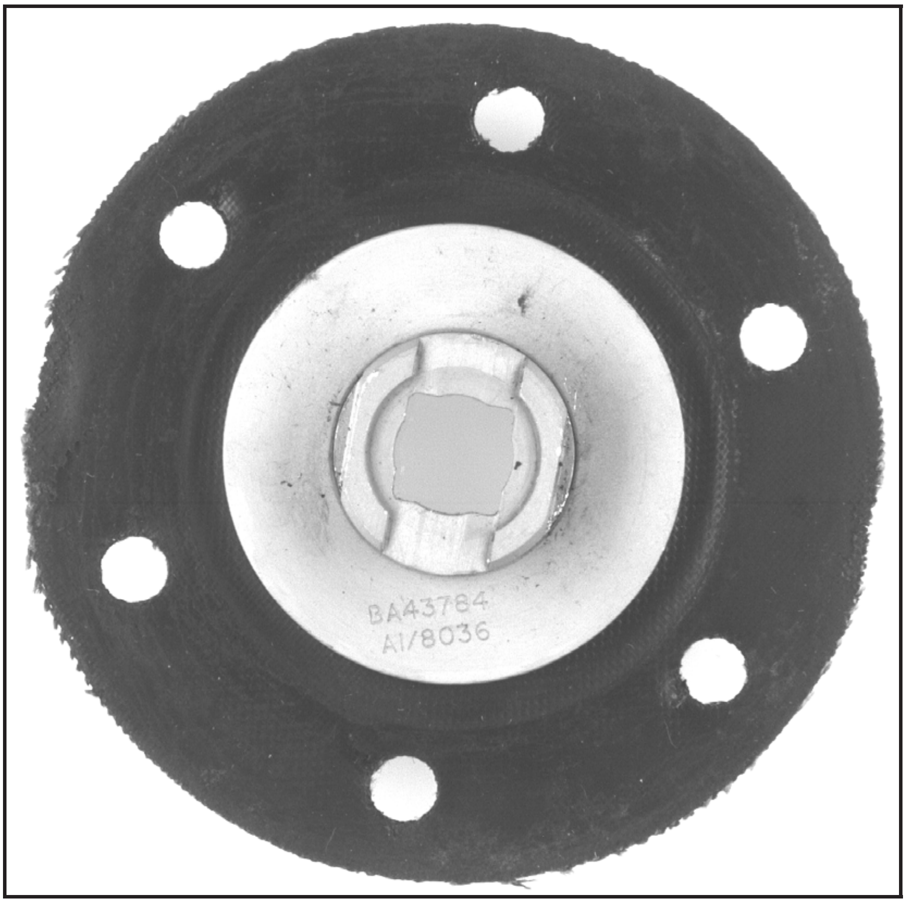

Figure 18 Acceleration Control Unit Diaphragm Face-2

Appendix F (Cont)

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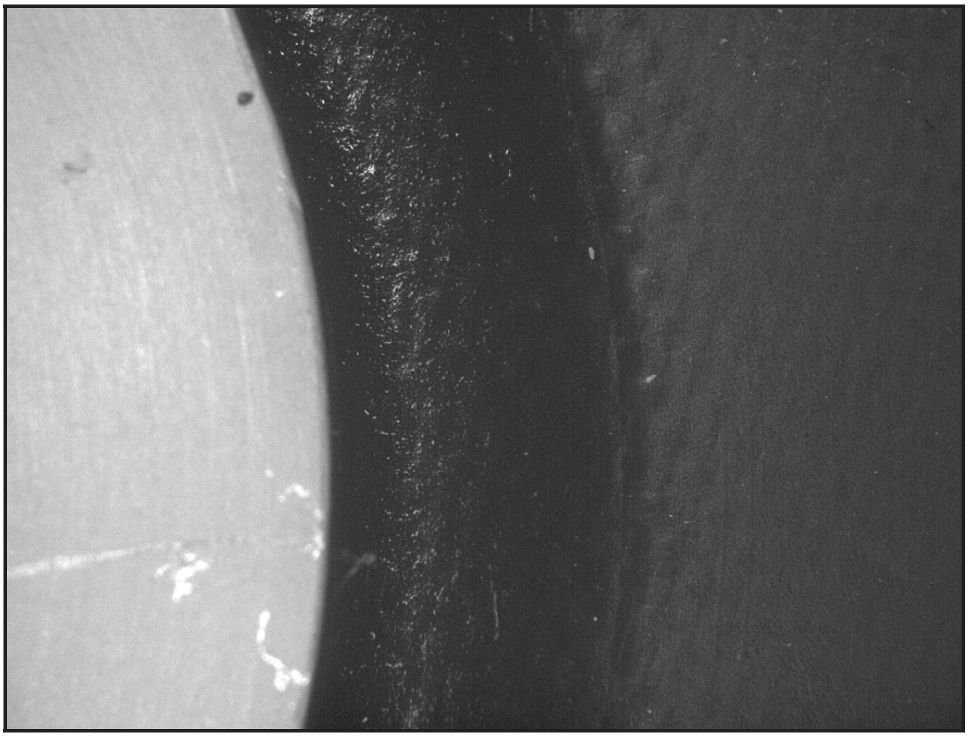

Figure 19 Acceleration Control Unit Diaphragm (Large) Face 1

Appendix F (Cont)

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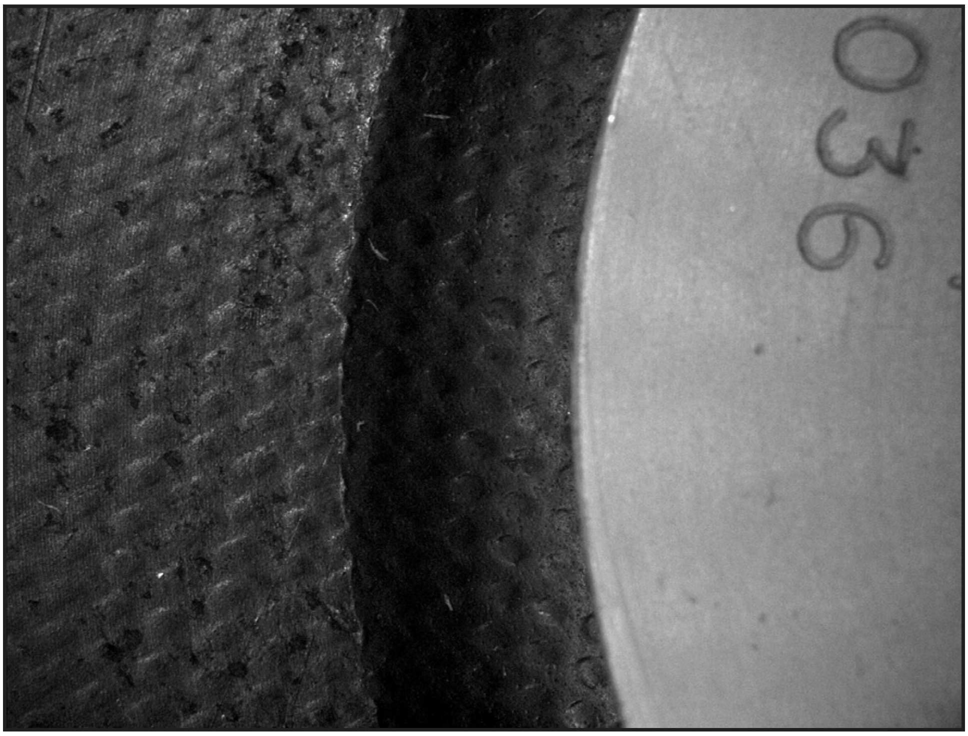

Figure 20 Acceleration Control Unit Diaphragm (Large) Face 2

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Figure 21 Barometric Pressure Control Solid Diaphragm

Appendix F (Cont)

3.0 OTHER ITEMS

3.1 The BPC Seal was a small solid Nitrile rubber disc with a beaded edge. The hardness of the seal was 76° IRHD which is an expected value for a material used for the application.

3.2 The beaded section of the BPC seal had taken a minor compression set but was within the original dimensions for a seal of this type, 0.084” (Ref. PN7061156).

3.3 A Nitrile O-ring of cross-section 0.070” and hardness 78° IRHD demonstrated some permanent deformation from the installed configuration but there was no evidence of degradation or ageing.

4.0 DISCUSSION

4.1 [redacted] GD64-1A Pump Diaphragm

4.1.1 This diaphragm was manufactured from two-plies of a Polychloroprene rubber proofed textile. Depending upon the date of manufacture the textile will either be cellulose type cotton (Fortisan) or polyester type (Terylene). Both textile types have similar properties.

4.1.2 The base polymer used for the rubber compound, Polychloroprene, has a known limited life in aviation kerosene.

4.1.3 However, when managed correctly any equipment containing a diaphragm manufactured from a Polychloroprene will not proceed to a point at which the resistance of the rubber composition to kerosene has been exceeded, *i.e. aged.*

4.1.4 The “Mud-Cracking” seen across the entire surface of the working convolution was a combined result of calendar life and exposure to kerosene.

4.1.5 The appearance would suggest there have been significant periods of non-operation where fuel will slowly degrade to form active chemical species (peroxides) that will then go on to attack the rubber.

4.1.6 The appearance of a “Tide-Mark” across the convolution was also evidence to suggest the diaphragm has been subject to periods of inactivity and where the fuel has been allowed to drain away.

4.1.7 Draining the fuel away from the diaphragm, whilst reducing the exposure to degrading species, also results in the rubber loosing flexibility and will crack because the fuel can no longer act as a plasticiser for the rubber.

4.1.8 The absence of plasticising fluid results in shrinkage of the rubber and then cracking.

4.1.9 The interchange of a plasticiser, added to rubber during manufacture, with kerosene when installed, is a well understood phenomenon. It is the reason why equipment containing diaphragms and rubber seals is not left static without constant exposure either to kerosene or inhibiting fluid, when not in use.

4.1.10 To establish the chemical state of the rubber in the convolution Fourier Transform Infra-Red (FTIR) was used. This technique was able to show a chemical signature of a Polychloroprene rubber used for this design of diaphragm and the difference between the degraded surface and unaffected flange area.

4.1.11 The appended trace appears to show a significant loss of the peak associated with an "alkyl halide" (C-Cl) at around 1280 wave numbers.

4.1.12 The loss of the alkyl halide is indicative of a chemical degradation process.

4.1.13 The degradation of the rubber on both faces of the convolution, due to the effects of age, loss of flexibility and chemical interaction with fuel have resulted in a diaphragm that has exceeded the known predictable functional capability of the design.

4.2 Acceleration Control Unit (ACU) Diaphragms

4.2.1 Both diaphragms operate in air and so are not exposed to the degrading effects of aviation kerosene or the presence of chemically active species that can arise in kerosene.

4.2.2 Both diaphragms, being manufactured from a Polychloroprene, have inherent resistant to atmospheric ozone which is known to affect other rubber materials such as Nitriles.

4.2.3 The compression set witnessed on the bead was significant and would be expected to cause leakage eventually, especially when sealing against a gas rather than a fluid.

4.2.4 The loss of adhesion between the rubber and the metal plate may have been a product of disassembly or evidence of a life limiting feature. There was no evidence, delamination, that air had entered the rubber textile construction.

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4.3 Barometric Pressure Control Solid Diaphragm

4.3.1 This was a solid rubber diaphragm manufactured from a Nitrile rubber which has an inherently greater resistance to aviation kerosene than Polychloroprene rubber.

4.3.2 There was no evidence of distress to the diaphragm.

5.0 CONCLUSION

5.1 With the exception of the Pump Diaphragm the components submitted were in an acceptable condition.

5.1.1 The condition of these components was typical of operating in an environment where calendar life, rather than thermal stress was a significant cause of any “ageing”.

5.1.2 The loss of adhesion seen on the smaller of the ACU diaphragms was likely to be a product of disassembly.

5.1.3 None of these components had reached a condition that had exceeded the know capability of the design or materials.

5.2 The Pump Diaphragm was significantly degraded by the effects of age, exposure to fuel and also air above the “Tide-Mark”.

5.2.1 The condition of the Pump Diaphragm was significantly more degraded than would be acceptable for a unit from a managed fleet. .

5.2.2 Whilst the diaphragm had not failed, its continued integrity would be severely affected by the degraded condition of the rubber both above and below the “Tide-Mark”.

5.2.3 The combined degrading effects of age, exposure to aviation kerosene and air have resulted in the pump diaphragm exceeding the known predictable functional capability of the materials it was manufactured from.

Appendix G

Mandatory Permit Directive 2016-001

Safety Directive

Civil Aviation Authority

MANDATORY PERMIT DIRECTIVE

Civil Aviation Authority

Number: 2016-001

Issue date: 7 October 2016

In accordance with Article 41(1) of The Air Navigation Order 2016, as amended, the following action required by this Mandatory Permit Directive (MPD) is mandatory for applicable aircraft registered in the United Kingdom operating on a UK CAA Permit to Fly.	
Type Approval Holder's Name: Rolls-Royce, de Havilland, Motorlet, Ivchenko	**Type/Model Designation(s):** Rolls-Royce Avon series, Rolls-Royce Viper series, Rolls-Royce Orpheus series, Rolls-Royce Nene series, Rolls-Royce Derwent series, de Havilland Goblin series, de Havilland Ghost series, Motorlet M701 series, Ivchenko AI-25 series
Title:	Engine Fuel System – Ageing Effects
Manufacturer:	Rolls-Royce, de Havilland, Motorlet, Ivchenko
Applicability:	Turbine engines of the following types fitted to ex-military jet aircraft: Rolls-Royce Avon series, Rolls-Royce Viper series, Rolls-Royce Orpheus series, Rolls-Royce Nene series, Rolls-Royce Derwent series, de Havilland Goblin series, de Havilland Ghost series, Motorlet M701 series, Ivchenko AI-25 series
Reason:	During an investigation following an accident involving a turbojet powered aircraft, CAA has been notified of significant deterioration in a rubber coated diaphragm used in the fuel pump of an engine fuel system. While not being considered a factor in the accident, the deterioration observed has been attributed by the engine manufacturer to ageing, chemical attack and air exposure. Such components were not lifed by the original manufacturer, since the extended calendar times in service now experienced in civil operation were not envisaged for the original military operation.

Reason Cont:	Once fitted to an engine, the life of rubber or rubber coated seals and diaphragms can be affected by various factors including fuel type, operating environment, compression load and time. Stale fuel in contact with diaphragms and seals over long periods with the aircraft parked or stored causes attack of rubber parts due to reaction with the material. Draining of fuel away from diaphragm and seal faces during periods of inactivity also leads to air exposure, loss of plasticity and subsequent cracking. During periods of inactivity, it is therefore important that regular running and/or inhibiting of fuel systems is carried out in accordance with the manufacturer's instructions. Note that many manufacturers specify the need for action to protect the fuel system after as little as 1 month of inactivity. Failure of an elastomeric component within a fuel system unit could lead to interruption of the fuel supply to the engine and therefore to partial or total engine failure. This unsafe condition, if not corrected, could lead to an emergency landing or the need to abandon the aircraft. Note: An unsafe condition is accepted by the CAA as: An unsafe condition exists if there is factual evidence (from service experience, analysis or tests) that: a) An event may occur that would result in fatalities, usually with the loss of the aircraft, or reduce the capability of the aircraft or the ability of the crew to cope with adverse operating conditions to the extent that there would be: i) A large reduction in safety margins or functional capabilities, or ii) Physical distress or excessive workload such that the flight crew cannot be relied upon to perform their tasks accurately or completely, or iii) Serious or fatal injury to one or more occupants unless it is shown that the probability of such an event is within the limit defined by the applicable certification specifications, or b) There is an unacceptable risk of serious or fatal injury to persons other than occupants, or c) Design features intended to minimise the effects of survivable accidents are not performing their intended function. For the purposes of this MPD, an unsafe condition is a "severe" failure of an elastomeric component such that continued safe flight and landing would be prevented. This MPD is raised to require a review of records of ageing fuel systems used on ex-military gas turbine jet engines to check that fuel system protection has been carried out in accordance with the manufacturer's instructions. CAA views this as an interim step while the investigation continues, with the potential for further action.
Effective Date:	10 October 2016

Appendix G (Cont)

Compliance/Action:	1) For any applicable turbine engine with calendar time greater than 20 years since last overhaul: Within 1 month or 10 flying hours from the effective date of this MPD, whichever limit is reached first: Examine the engine records subsequent to the release from military service and record evidence found of: a) Regular running of the engine, shown to be at intervals and to methods in accordance with manufacturer's instructions and b) Inhibition of the engine fuel system in accordance with manufacturer's instructions after any period of inactivity specified in the relevant operating manuals. If, following examination of the records, it can be shown that the engine has been run at the specified intervals and inhibited in accordance with the manufacturer's instructions, the requirements of this paragraph can be considered to have been met and paragraphs (2) and (3) are not applicable. 2) Following examination of the records, for any engine which cannot be shown to have been run at specified intervals and inhibited in accordance with the manufacturer's instructions, within three months from the effective date of this MPD, conduct a failure analysis of the elastomeric components in the engine fuel system units and determine the seriousness of each mode of failure. Guidance material is provided with this MPD which includes the classification of the different levels of seriousness. If there are no "severe" failures, i.e. failure of any elastomeric component within any particular fuel system unit that would prevent the aeroplane continuing safe flight and conducting a normal landing, the design of the fuel system can be considered acceptable for the purposes of this MPD and paragraph (3) is not applicable. Note: Such a failure analysis is considered an Alternative Method of Compliance (AMOC) and requires separate CAA acceptance. The authors of the analysis and the analysis method to be used are to be acceptable to the CAA. 3) If the failure analysis identifies "severe" failures, the AMOC must be enhanced and include: a) Mitigation, acceptable to the CAA, of the "severe" failures b) Based on the outcome of the failure analysis, development of an ongoing aeroplane level performance monitoring programme may be required to assess deterioration within the fuel system and remove parts from service before this reaches an unacceptable level. c) Based on the outcome of the failure analysis, a continuing airworthiness programme for the engine fuel system items, potentially including a programme of stripping of fuel system units, may also be required.

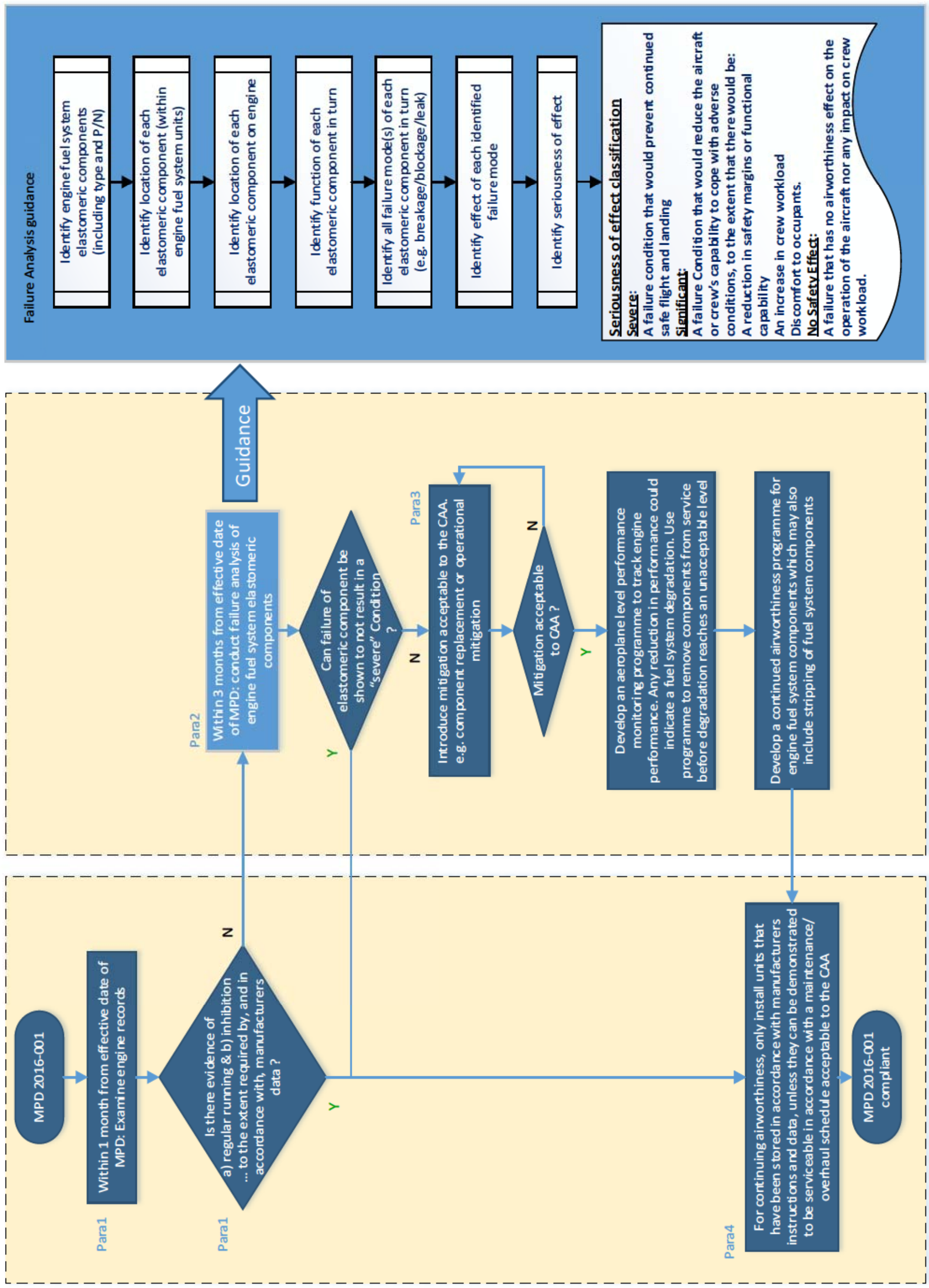
Appendix G (Cont)

Compliance/Action Cont:	4) From the effective date of this MPD, do not install engine fuel system units which have not been stored in accordance with manufacturer's instructions and any time limits specified unless they can be demonstrated to be serviceable in accordance with a maintenance/overhaul schedule acceptable to the CAA.
ENSURE COMPLIANCE WITH THIS MPD IS RECORDED IN THE AIRCRAFT LOGBOOK	
Reference Publications:	Nil
Remarks:	1. This MPD was posted on 18 February 2016 as PMPD 16-01 for consultation until 29 February 2016. 2. If requested and appropriately substantiated, the CAA may accept Alternative Methods of Compliance to this MPD. Application for an Alternative Method of Compliance (AMOC) must be made to the CAA and, if agreed, the CAA will issue a written acceptance that confirms the AMOC meets the necessary compliance requirements. 3. Enquiries regarding this Mandatory Permit Directive should be referred to: GA Unit, Civil Aviation Authority, Safety and Airspace Regulation Group, Aviation House, Gatwick Airport South, West Sussex, RH6 0YR. Telephone: +44 (0)1293 573988 E-mail: ga@caa.co.uk

Appendices

Appendix G (Cont)

MPD 2016-001 Engine Fuel Systems – Ageing Effects
Guidance Material (GM)



Appendices

Appendix G (Cont)

GM to Engine Fuel System – Ageing Effects. Elastomeric Component Failure Analysis

Company Name:
Aircraft type/Serial:
Engine type/model:

Elastomeric component definition *What is it? Where is it? What does it do?*						Elastomeric component failure analysis *What could possibly go wrong? How serious is it?*		
No.	Type (Seal, diaphragm, etc.)	Part number	Location in system (pump, connection, etc.)	Location on engine (high vibration/hot/swamp – Visible/not visible when installed)	Function	Functional failure mode (Leak, blockage, etc.)	Functional effect of failure (Degraded performance, lost function, etc.)	Severity of effect[1]
1	Diaphragm	AB-123-XY-2	Fuel Pump	Visible when installed [illegible]con[illegible]stor[illegible]se when ac[illegible] i.a.w. [illegible]nual	Primary function [illegible] fuel fe[illegible] re[illegible]ation Seco[illegible]ry function e.g. overspeed protection	Leak/blockage [illegible]eak/[illegible]ocka[illegible]	Loss of fuel feed [illegible]gin[illegible] [illegible]rust re[illegible]tion/shutdown) E[illegible]ess[illegible]l feed [illegible]xces[illegible] [illegible]gine sp[illegible]/possible trigger of oversp[illegible]d protec[illegible]n) Loss of [illegible]e[illegible] on by diaphragm (Overspeed protection provided by two systems rather than three) Unintended overspeed activation (engine shutdown)	Significant/Severe Significant/Severe Significant Severe
2	Etc.							

The severity of each functional failure effect is to be classified in accordance with the following criteria:

- **Severe:**
  A failure that would prevent continued safe flight and landing.
- **Significant:**
  A failure condition that would reduce the aircraft or crew's capability to cope with adverse conditions, to the extent that there would be:
  - A reduction in safety margins or functional capability
  - An increase in crew workload
  - Discomfort to occupants
- **No Safety Effect:**
  A failure that has no airworthiness effect on the operation of the aircraft, nor any impact on crew workload.

[1] Failures classified as Severe require mitigation. The example shown that three of the identified four failures could be classified as severe. However, any one failure mode of each unit classified as severe drives the need for mitigating action. Such mitigation needs to be acceptable to the CAA.

Appendix H

Report on Data Gathering Flying Related to the Accident to G-BXFI

1. Introduction One aspect of the investigation into the reasons why, on 22 August 2015 at the Shoreham air show, Hunter T Mk 7 G-BXFI struck the ground during the latter stages of a looping manoeuvre was to undertake data gathering flying in an appropriate airframe in order to ascertain how and why the apex airspeed and altitude were achieved and why the aircraft impacted the ground during a subsequent pull-through. This report details the flying performed and presents the data gathered along with relevant discussion and conclusions. It also includes some relevant analysis of the cockpit GoPro video. In order to help understand the manoeuvres flown some of the relevant theory is covered below.

a. Factors Determining the Apex Height and Airspeed of Looping Manoeuvres The apex of a looping manoeuvre is the point at which the maximum height is achieved and is coincident with the point at which the minimum airspeed occurs. The aircraft is in a wings level, essentially inverted attitude although it will actually be slightly nose low if a high angle of attack and high pitch rate is maintained through the apex. In a straight loop entered from level flight and constant airspeed there are three factors that determine the apex airspeed and the increase in height above the entry height, namely entry airspeed, engine thrust and the manner in which the pilot flies the pull-up in terms of the pitch rate/normal acceleration/Angle of Attack (AOA) that is used. If the pilot also 'bends' the loop during the first, upward half of the manoeuvre (i.e. applies a roll rate for a brief period such that the vertical plane of the loop is adjusted to achieve a different heading on completion of the manoeuvre to that at pull-up) the apex height and airspeed will be affected.

b. Straight Loop In a straight loop the interrelationship between airspeed, thrust and pull-up technique is discussed below, and this description assumes the same entry height, density altitude and all up mass, and entry with power for level flight for the entry speed. The entry kinetic energy (airspeed) is partially converted into potential energy (height) during the pull up. In addition, the overall energy state of the aircraft will be reduced somewhat during the pull up due to the increased lift dependent drag generated by the higher AOA. How much of the airspeed is converted into height is essentially a function of how long it takes to reach the apex of the loop and this time depends upon the pitch rate of the aircraft, which the pilot normally controls by flying a value of normal acceleration (g) or AOA (the latter often by feel as a certain level of buffet), or by a cadence (pitch rate) that is judged based on experience and practise. For a given entry speed and thrust, the greater the normal acceleration/AOA used by the pilot the lower will be the apex height, and unless the increase in lift dependent drag is excessive this will also result in a higher apex airspeed. Conversely, if the pilot uses a slacker pull-up a higher but slower apex will be achieved. However, if the pull-up is too slack then the aircraft may decelerate to zero airspeed before the apex is reached. Therefore, for a given entry airspeed and engine thrust setting there will always be a maximum height that can be achieved whilst still maintaining the required speed to complete the manoeuvre. But if with the same entry speed more thrust is used, the pilot can fly a slacker pull-up and thereby achieve a greater apex height whilst still maintaining the required airspeed to safely complete the manoeuvre; note that apex height will not be increased significantly if the thrust is increased but the same pull-up g/AOA/pitch rate is applied. Similarly, for a given thrust the apex height can be increased by having a higher entry speed. The height gained will always be relative to entry height so if entry airspeed, thrust and pull-up g/AOA/pitch rate are fixed, the apex height will increase if entry height is increased.

c. 'Bent' Loop If a roll component is introduced into the upward half of the loop in order to 'bend' it, for a given entry speed, thrust setting and pull-up g/AOA, the aircraft will reach the apex of the manoeuvre sooner, resulting in lower height and higher airspeed than in a straight loop. Therefore, combined with the factors discussed in paragraph 1b above, a low apex height will be achieved if a looping manoeuvre is flown from a low entry airspeed with a maximum pitch rate pull-up and with a 'bend' introduced during the pull-up.

2. Test Philosophy Two specific cases were investigated during this assessment. The first, which constituted the majority of the assessment, related to the parameters of the accident manoeuvre. The second case was flown using the nominal parameters for the manoeuvre that the accident pilot had stated during interview. The values for the accident manoeuvre parameters were derived from various sources: IAS and JPT from cockpit GoPro video and RPM from analysis of the GoPro audio. The timing of the aileron application during the upward half of the manoeuvre was based on a lateral stick deflection observed on the GoPro video. The apex height was deduced from Mode C radar traces. No data was available for the g or AOA during the manoeuvre but because the apex height was so low, the upward half of the manoeuvre was assumed to have been flown with the maximum pitch rate achievable which required maximum instantaneous lift i.e. in light to moderate buffet. The effects of thrust variations upon the accident manoeuvre were assessed because of thrust changes during the accident manoeuvre.

3. Sortie Details Two data gathering sorties totalling 1 hour 25 minutes of airborne time were flown from RAF Scampton on 19 October 2015. Following analysis of the data from these sorties, and with further information having been gathered during other aspects of the investigation, a decision was made to fly a third sortie. Therefore, a 55 minute sortie was flown on 4 December 2015, again from RAF Scampton, in order to gather more data. All times quoted are UTC.

4. Pilot Details The pilot who flew the data gathering sorties was a qualified military test pilot and test pilot instructor whose was in current flying practise on several military fast-jet types. He was current to fly military registered Hunters and held a UK ATPL with a Type Rating Exemption for Hawker Hunter aircraft. He held a UK Display Authorisation for the Hunter and was a Display Authorisation Examiner for Class G aircraft (which covers the Hunter). He had Hunter display experience under both UK Military and UK CAA regulations. He had over 1000 flying hours in the Hunter and over 10 000 hours total flight time.

5. Aim and Objectives The aim of the sorties flown was to gather data to gain an understanding of the accident manoeuvre. There were four specific objectives:

a. To ascertain if, having reached the apex of the accident manoeuvre, it was possible to have flown an alternative 'escape' manoeuvre such that a collision with the ground could have been avoided.

b. To identify if, having reached the apex of the accident manoeuvre, it was possible to have continued the pull through manoeuvre as attempted and have avoided a collision with the ground.

c. To identify the factors that resulted in the flight conditions achieved at the apex of the accident manoeuvre.

d. To ascertain if a 'bent loop' manoeuvre could be flown safely if entered with a different combination of airspeed, pull-up technique and power to those used in the accident manoeuvre, specifically the nominal parameters declared by the accident pilot

6. Airframe Used for Data Gathering The aircraft flown for the data gathering was a Hawker Hunter F Mk 58 which was owned and operated by HHA Ltd. It was a UK MAA registered aircraft with the tail number ZZ190 and was flown in accordance with MAA regulations. It had certain specific differences from G-BXFI as detailed below. Any aspects that are relevant to the performance and flying qualities of the tasks flown that are not mentioned below were essentially identical between the two airframes.

Appendix H (Cont)

a. Engine ZZ190 was fitted with an Avon Mk 207 engine which produced 10 150 lbs of thrust under static ISA sea level conditions. G-BXFI was fitted with an Avon Mk 122 engine which produced 7575 lbs of thrust under the same atmospheric conditions. Rolls Royce provided data to indicate the RPM required to be set on a Mk 207 engine in order to produce the same thrust as for a specified RPM on a Mk 122 engine. Therefore, it was possible to fly the tasks with thrust settings equivalent to those used in the accident manoeuvre as specified in Table 1.

Mk 122 RPM	Equivalent Mk 207 RPM	Relevance
8100	7400	Maximum T Mk7 thrust
7950	7250	Thrust for lift boundary comparison
7500	6900	RPM setting at pull-up
7200	6600	RPM setting at apex

Table 1 - Equivalent Power Settings

b. External Stores Configuration G-BXFI was fitted with an inboard and an outboard pylon on each wing with a 100 gal external fuel tank carried on each inboard pylon. ZZ190 had aerodynamically identical pylons and fuel tanks fitted but in addition had a Swiss shoulder pylon fitted underneath each wing root. This had the effect of increasing drag slightly, thereby reducing the airspeed of ZZ190 slightly for a given thrust setting and making that the worst case airframe. The shoulder pylons should have had no other effects upon performance or flying qualities.

c. Nose Shape A Hunter T Mk7 has a two-seat, side-by-side cockpit that results in its fuselage having a wider nose than that of a single-seat F Mk58 and, theoretically, the difference in nose shapes could result in a difference in the overall lift produced by the airframe which could affect height loss in the downward half of a looping manoeuvre. Data from weapon aiming sight depression calculations indicated that when in a 15˚ dive at low level and 400 KIAS the AOA at which a T Mk 7 flew was 11.6 mRads (0.66˚) less than that for a single-seat variant, implying that the T Mk7 flew more nose low for given conditions at this speed and at close to 1g. The mathematics of this result from the T Mk7 having a lift curve slope (relationship between coefficient of lift and AOA) that was 0.36% greater than that of the F Mk58 (i.e. a T Mk7 will have a very slightly greater increase in lift for a given increase in AOA than a F Mk58 will), plus an angle between the 'Zero Lift Line' (ZLL) and the 'Longitudinal Fuselage Datum' (LFD) that was 8.5 mRads (0.49˚) greater than that of the F Mk58 (LFD below the ZLL). Overall, these are very small differences with respect to the instantaneous turn performance of the aircraft and this data relates to low AOA conditions. No comparative lift data at high AOA was available and, therefore, some tests were flown to ascertain if any differences existed at the AOAs relevant to high AOA looping manoeuvres.

d. Flaps The flaps on the two relevant marks of Hunter were identical except that the F Mk58 had a small cut-out on the inboard corner of each trailing edge to allow larger fuel tanks to be carried. Within the experimental accuracy of the test data, the resulting difference in lift coefficient due to these cut-outs is probably insignificant, and no difference related to the modification standard of the flaps is annotated in the performance manuals with respect to any performance data.

e. All Up Mass and Centre of Gravity

(1) ZZ190 Sorties 1 and 2 with Nose Ballast The All Up Mass with full fuel was 20703 lbs with a C.G position of 4.966 ins aft of datum. The Zero Fuel Mass was 16053 lbs with a C.G position of 7.333 ins aft of datum. Start up fuel mass was 4650 lbs.

(2) ZZ190 Sortie 3 without Nose Ballast The All Up Mass with full fuel was 20121 lbs with a C.G position of 5.109 ins aft of datum. The Zero Fuel Mass was 15471 lbs with a C.G position of 7.608ins aft of datum. Start up fuel mass was 4650 lbs.

7. G-BXFI Weight and Balance

a. Aircraft Details The All Up Mass with full fuel was 18814 lbs with a C.G position of 3.710 ins aft of datum. The Zero Fuel Mass was 14087 lbs with a C.G position of 8.821 ins aft of datum. Based on a SG of 0.778 (measured from the bowser at refuel) start up fuel mass was 4824 lbs and internal fuel was 3270 lbs.

b. All Up Mass and CG Position at Impact The Hunter T Mk7 uses approximately 400 lbs of fuel for start-up, taxi and take-off (SUTTO) with the end of this phase being approximately 1 minute after take-off for the sorties considered in this report. The Aircrew Manual (Hunter T Mk7 & 7A Aircrew Manual', AP 101B-1302 & 3-15, 3rd Edition, AL9 dated Sep 1992) quotes 280 lbs for SUTTO but experience has shown that this is a very optimistic figure and, empirically, 400lbs has been accepted as an average value . On the accident sortie the take-off time was 1204 with the first radar trace at 1206:32 when 7.6 nm SSE of North Weald. The final radar trace was at 1222:19. The radar traces show the ground distance flown from first plot to impact was 75.4 nm with a flight time over this distance of 15 minutes 47 seconds. This gave a mean groundspeed of 287 kts, which was rounded to 300 kts for the purposes of using Aircrew Manual fuel consumption data for the transit from North Weald and initial display manoeuvres. The performance data in the Hunter T Mk7 Aircrew Manual indicated that the fuel consumption at this speed should be 52 lbs/min. With the SUTTO phase being complete approximately 1 minute after take-off, the total time for which a mean fuel consumption of 52 lbs/min can be assumed was approximately 17 minutes, which would result in a theoretical fuel usage for this phase of 884 lbs. Therefore, for a start up fuel weight of 4824 lbs the fuel weight at impact was, based on the above values of fuel used for SUTTO, the transit and the start of the display, 3540 lbs giving an AUM of 17 627 lbs. The cockpit fuel gauges indicated that the internal tanks were full at impact confirming that the fuel weight was greater than 3270 lbs. However, the assumptions in the above calculations do contain some unquantifiable errors and therefore the calculated figure has been rounded to a best estimate for All Up Mass at impact of 17600 lbs. This would equate to a fuel quantity in the external underwing tanks of 326 lbs and a C.G position of 3.97 ins aft of datum.

8. Significant Weight and Balance Differences Between G-BXFI and ZZ190 The Zero Fuel Mass (ZFM) of ZZ190 for sorties 1 and 2 when the nose ballast was fitted was 1966 lbs greater than that of G-BXFI; its ZFM for sortie 3 when the nose ballast had been removed was 1384 lbs greater than G-BXFI. Based on this and with knowledge of the fuel weight in any given manoeuvre flown in ZZ190, the difference in its AUM compared to G-BXFI at the time of the accident can be ascertained. G-BXFI had a slightly further aft c.g. position with zero fuel and slightly further forward c.g. position with full fuel than ZZ190. Therefore, the tests were within the range of c.g positions for G-BXFI. Any c.g. differences would have resulted in a slightly different tailplane angle for trim at a given airspeed but the effect of this upon the difference in instantaneous turn performance would have been be negligible.

9. Sortie Details

a. Sortie 1: Take-off 1010, land 1054. Manoeuvres flown: Escape manoeuvres, minimum radius loops.

b. Sortie 2: Take-off 1303, land 1342. Manoeuvres flown: Straight and bent loop comparison.

c. Sortie 3: Take-off 1221, land 1314. Manoeuvres flown: Optimum entry condition bent loops, minimum radius loops, lift boundary wind up turns.

10. Meteorological Conditions The relevant meteorological conditions at RAF Scampton (airfield elevation 202 ft) for the sorties flown were:

a. Sortie 1: QFE 1018 hPa; QNH 1026 hPa; OAT +12˚C; Dew point +9˚C.
Density altitude -391 ft.

b. Sortie 2: QFE 1018 hPa; QNH 1025 hPa; OAT +13˚C; Dew point +5˚C.
Density altitude -272 ft.

c. Sortie 3: QFE 1014 hPa; QNH 1021 hPa; OAT +10˚C; Dew point +7˚C.
Density altitude -482ft.

d. Wind Data The surface winds were observations taken at RAF Scampton. The 2000 and 5000 ft winds were estimates by the Meteorological Office at RAF Waddington.

Sorties 1 and 2

Time	Surface wind	2000 FT wind	5000 FT wind
0950	010 06 KT	020 15 KT	060 10 KT
1050	060 10 KT	040 15 KT	070 10 KT
1250	040 08 KT	040 15 KT	010 05 KT
1350	030 09 KT	040 10 KT	350 05 KT

Sortie 3

Time	Surface wind	2000 FT wind	5000 FT wind
1150	230 17 KT	260 40 KT	280 25 KT
1250	230 16 KT	260 40 KT	280 25 KT
1350	210 15 KT	260 40 KT	260 45 KT

11. Shoreham Meteorological Data The relevant meteorological data for Shoreham (airfield elevation 7 ft) at the time of the accident were: QNH 1013; OAT +24˚C; Dew point +17˚C. Density altitude 1310 ft.

12. Accident Video and Photographic Data Sources of information in establishing the test parameters for the data gathering sorties and analysing the aircraft's flightpath included the GoPro camera video recordings from the accident flight plus ground-based video recordings. The pertinent aspects are detailed below:

a. Airspeed The right hand instrument panel ASI was recorded on the cockpit GoPro. The analysis of this video that had been completed at the time of the data gathering flying indicated an airspeed at pull up of 300 KIAS and a minimum airspeed at the apex of 100 KIAS. The maximum speed during the second half of the accident manoeuvre was analysed as 210 KIAS which was reached at approximately 45˚ nose down erect; it then remained essentially constant until just prior to impact. Subsequent more detailed analysis has indicated that the airspeed at pull-up was 310 ± 15 KIAS and that at the apex was 105 ± 2 KIAS. Discussion of airspeeds in this report are based upon the values assumed at the time of the data gathering flying.

Appendix H (Cont)

b. Engine Thrust The video recording of the take-off showed a maximum Jet Pipe Temperature (JPT) of approximately 680˚C. At pull-up for the accident manoeuvre the JPT was approximately 540˚C. During the accident manoeuvre the JPT gauge indicated a minimum of approximately 480˚C and a maximum of approximately 550˚C. This indicated that the engine was not developing full thrust at pull-up and that the thrust did vary during the manoeuvre. In particular, the JPT reduced after the initial pull-up, indicating a further reduction in thrust, and then increased slightly as the apex was reached. It was not possible to replicate these thrust variations precisely and therefore test manoeuvres were flown using a fixed thrust setting or with a single variation of thrust at the apex to achieve worst or best case data.

c. Flying Control Status The Hunter flight control system incorporates 'hydro-boosters' for the elevator and ailerons which enable stick movements to be made with very low applied forces. If the powered flying controls are switched off or if the hydraulic system fails, control of the elevator and ailerons is purely manual and the forces required to move the stick are very high. During the initial run in, the first manoeuvre of the display and for parts of the final manoeuvre the top of the right seat stick can be seen. When pilot inputs were made to move the stick, the rate of movement observed was at times greater than would have been possible if the powered flying controls had been inoperative, including during the final manoeuvre. Therefore, it is reasonable to assume that the powered flying controls were functioning correctly throughout the flight and had not reverted to, nor been selected to, Manual mode. In addition, the switch for the Tailplane and Elevator Interconnection (sometimes referred to as the Follow-Up Tailplane) can be seen to be in the OFF position which is normal when flying at speeds less than 0.9M.

d. Accelerometer At the start of the take-off roll, the instantaneous needle plus the maximum and minimum needles all indicated slightly under +1g. During the take-off roll the vibrations caused the maximum and minimum needles to be moved (which is normal on a rough runway surface) and the instantaneous needle to read approximately 0.5g. During the run-in for the display the maximum and minimum pointers showed less than immediately after take-off, indicating that the pilot probably had pressed the 'reset' button at some point in flight. From commencing the display until reaching approximately 30˚ nose down erect in the latter stages of the final manoeuvre the accelerometer needles did not move, with the instantaneous pointer showing 0g, the maximum needle showing +4g and the minimum needle showing -1g. On reaching this point in the manoeuvre camera vibration started, almost certainly caused by heavy airframe buffet due to being at high angle of attack. The maximum pointer then moved to and maintained full scale deflection high (+10 g) followed shortly after by the instantaneous needle moving to and stabilising at +2g. The minimum needle then went to full scale deflection low (-5g). These g values could not have been achieved with the indicated airspeed and observed pitch rate of the aircraft. All of the aforementioned indications demonstrated that the accelerometer was not functioning correctly. When flying a looping manoeuvre in aircraft such as the Hunter the pilot normally applies, and initially maintains, a given value of g at the pull up in order to achieve the desired profile and make the required apex height. Therefore, if the accelerometer is not working correctly the pilot is denied an important cue for helping to achieve the desired apex height and thus flying the loop correctly. So saying, for upward half loops when there is no intention to pull down through the vertical and a gate height is not required the aircraft is often flown by feel at a certain level of buffet and for such a manoeuvre an accelerometer is not required. Another implication of not having a correctly functioning accelerometer is that at speeds above corner speed (the minimum speed at which the g limit can be reached) the pilot has no indication of whether or not he has exceeded the g limit of the aircraft. This last factor could lead a pilot to attempt to fly at slower than normal speeds such that the g limit could not be reached and thus avoid an overstress.

e. Flightpath Immediately Prior to Impact During the downward portion of the final manoeuvre vibration was observed in the GoPro video throughout the 3 to 4 seconds before impact. This was almost certainly due to the aircraft entering heavy buffet at high angle of attack. Shortly after onset of the vibration the aircraft rolled approximately 15˚ left then rolled back towards wings level. At 1.12 seconds to impact the aircraft reached a level pitch attitude (but still with a significant rate of descent) and then pitched rapidly nose up to 13.6˚ with an associated increase in rate of descent. At no stage during the final seconds prior to impact did the pitch attitude or pitch rate reduce. Specific stall data for the Hunter at the airspeed, normal acceleration and flap setting that existed just prior to impact was not available but some generic comments on the Hunter's stalling characteristics can be made. The stall (here defined as the angle of attack that produces the maximum lift coefficient) usually occurs at between approximately 25˚ and 35˚ depending on flap setting and airspeed (as a function of both Mach number and Reynold's number). The characteristics of the stall are typically very heavy buffet, a large increase in drag leading to a high rate of descent and/or rapid deceleration, and often wing rock through up to about ±15˚ at a frequency of approximately 0.5 Hz. In addition, having a swept wing there is still a significant, albeit reduced, coefficient of lift past the stall, and in an accelerated stall (i.e. when the normal acceleration is greater than 1g) at airspeeds such as existed during the final stages of the accident manoeuvre the elevators will still be effective such that an additional aft stick input at the stall will probably still result in an initial increase in nose up pitch rate, increase in angle of attack and a resultant increase in drag. Therefore, the video evidence is consistent with the aircraft entering an accelerated stall in the final few seconds of the accident manoeuvre and then being pulled into the post-stall regime which was maintained until impact.

13. Data Gathering Manoeuvres Flown

a. Upward Half Loop and Escape Manoeuvre These manoeuvres were flown in order to ascertain the height loss that resulted if, at the apex, a decision was made to abort a planned downward pull-through manoeuvre and then to roll erect and regain level flight. They were commenced at a nominal height of 200 ft (altimeter reading with QFE set), at 300 KIAS and with 7400 RPM set. Some were flown with 1 notch of flap (16˚) and some with 2 notches of flap (23˚) selected, and the flap setting remained constant throughout the manoeuvre. The upward half loop phase to the apex was flown in light buffet throughout (ie. at maximum useable AOA), with the initial normal acceleration being approximately 4g. The escape manoeuvre involved moving the stick forward to achieve zero pitch rate then rolling through 180˚ back to erect flight using 1/2 aileron deflection and with the rudder restrained at neutral. The rolls were commenced at various pitch attitudes between when the nose reached the horizon (approximately 5˚ - 10˚ nose down) to as low as 45˚ nose down. On achieving wings level an aft stick input was made to recover the aircraft to level flight in light buffet. The power either remained constant at 7400 RPM or was selected to idle at the apex of the manoeuvre.

b. Minimum Radius Loop The aim of these manoeuvres was to identify the minimum height loss that could be achieved if, at the apex, a decision to continue with a looping manoeuvre was made. The manoeuvres were entered at a nominal height of 2000 ft on sortie 1 and 1500 ft on sortie 3 (altimeter reading with QFE set), at 300 KIAS with 7400 RPM set on sortie 1 and 300 KIAS and 7200 RPM on sortie 3, some with 1 notch and some with 2 notches of flap. The manoeuvres were flown in light buffet throughout (i.e. at maximum useable AOA) with the exception of one where the pull was slackened immediately prior to the apex in order to allow the airspeed to decay to the required value. At the apex the power was either maintained, the throttle selected to idle, the RPM reduced to 6600, or full throttle selected. On all but one manoeuvre the flaps remained constant throughout, the one exception being a selection from 2 to 4 notches (38˚) at the apex.

c. 'Bent' Loop A series of upward half loops was flown to investigate the difference in airspeed and height at the apex between a straight upward half loop and one that was 'bent' through 45˚ or 90˚. The 'bent' loops were flown with a left rolling phase commenced, as per the accident manoeuvre, approximately 5 seconds after pull up (just before the vertical) such that the exit heading of the loop would be 45˚/90˚ greater than the heading at pull up. The pull ups were flown from a nominal height of either 100, 150 or 200 ft (altimeter reading with QFE set) with 1 notch of flap set and at a speed of 290 or 300 KIAS. Power settings were either 7400, 7200 or 7000 RPM. The pull-ups were flown in light buffet throughout (i.e. at maximum useable AOA), including during the rolling phase. The height and airspeed data required was noted at the apex, and for safety of flight these manoeuvres were all terminated just past this point in an escape manoeuvre flown in the manner described in paragraph 13.a above.

d. Nominal Entry Parameter 'Bent' Loop The aim of these manoeuvres, flown on sortie 3, was to ascertain the apex height and airspeed that would be achieved if a 90˚ bent loop was flown using the accident pilot's declared nominal entry conditions. These were entered at 350 KIAS and 200 ft QFE with 7400 RPM set (equivalent to full power in a T Mk7) and with an initial pull up at 4g. On decelerating through 300 KIAS the required flap setting (1 or 2 notches) was selected. Approaching the up vertical the pull was slackened, albeit with a continuing nose up pitch rate and with more than 1g normal acceleration maintained, and left aileron was applied to roll through 90˚. On reaching the apex, power was reduced to approximately 6600 RPM and a pull through flown. On accelerating through 300 KIAS the flaps were raised and the aircraft was levelled at 500 ft QFE.

e. Photographic 'Bent' Loops Two upward bent loops were flown purely for ground photographic purposes with the aim of identifying the flap angle set on G-BXFI. These were flown with full F Mk58 power and so were not representative of T Mk7 performance and are not reported upon here.

14. Data Sources and Accuracy

a. Throughout this report, the data quoted was gathered from the following sources and to the specified reading resolution:
- Indicated Airspeed: Cockpit ASI to the nearest 5 kts.
- Altitude: Cockpit altimeter to the nearest 100 ft for sorties 1 and 2, and the nearest 50 ft for sortie 3. In addition, the accuracy of the altimeter was considered to be +/- 50 ft.
- Fuel weight: Cockpit fuel gauges generally to the nearest 100 lbs although some readings were taken to the nearest 50 lbs (fuel only gauged with a total fuel weight of 2850 lbs and below).

b. It is assumed that for the low altitude tests flown changes in pressure altitude were equal to changes in density altitude ie. the ambient temperature and dew point lapse rates were the same. Therefore, density altitudes quoted are based on the calculated airfield surface density altitude plus altimeter reading with QFE set.

15. Results and Discussion

a. Turn Performance Comparison Between Hunter T Mk 7 and F Mk 58 The only significant difference in build standard with respect to instantaneous turn performance (lift produced by the aircraft) between a Hunter T Mk7 and F Mk58 was the nose shape. Data was available from an Empire Test Pilots' School (ETPS) Stalling report written by the assessment pilot on the accelerated stalling performance of a T Mk7 of identical build standard to G-BXFI and which also had an AOA probe fitted. The manoeuvre reported upon was reproduced in ZZ190 with an equivalent thrust setting for comparison. The manoeuvre was a Wind-up Turn (a constant Mach number, constant power descending turn flown with a slow g onset rate to give pseudo-stable data) flown at 0.7 IMN (~300 KIAS) and a datum altitude of 25 000 ft. The power set in the T Mk7 was 7950 RPM and the AUM was 18 000 lbs; 7250 RPM was set in the F Mk58 for thrust equivalence. The relevant data is in Table2 below.

	T Mk7	F Mk58	
AUM (lbs)	18 000	18 070	17 770
Pressure Altitude (ft)	25 000	24 600	23 500
Buffet onset g	3.0	3.0	--
Equivalent g (1)	3.04	--	--
Buffet onset AOA (degs)	17	--	--
Heavy buffet g	4.0	--	--
Equivalent g (1)	4.32	--	4.3
Heavy buffet AOA (degs)	24	--	--

Notes: 1. T Mk7 data value corrected to F Mk58 test weight and altitude.

Table 2- Instantaneous Turn Performance Data

The ETPS report indicates that after stabilising in heavy buffet the AOA could be increased further from 24˚ to 26˚ but that no increase in g occurred. Therefore, the heavy buffet data presented was the maximum instantaneous turn performance for the T Mk7. From the F Mk58 sortie, normal acceleration data was recorded on a specially installed data logger. The normal acceleration trace from the data logger was affected by the airframe buffet which generated high frequency noise. The amplitude of the noise was a band of approximately 0.75g to 1g at buffet onset and approximately 1.5g to 2g in heavy buffet. However, the values of the T Mk7 normal accelerations corrected to the test weights and altitudes that were flown in the F Mk58 (3.04g at buffet onset and 4.32g in heavy buffet) fell in the middle of the noise band of the normal acceleration trace, indicating that there was no significant difference in instantaneous turn performance between the two Marks at the tested conditions. Therefore, the small AOA differences at low AOA and higher speeds resulting from the different nose shapes, as discussed in paragraph 6c, did not result in a measurable difference in instantaneous turn performance between the T Mk7 and F Mk58. Therefore, the lift related data gathered in the F Mk58 is representative of a T Mk7.

b. Escape Manoeuvres During sortie 1, six upward half loop manoeuvres were flown specifically to identify the handling characteristics and height loss during a rolling escape manoeuvre flown post apex as described in paragraph 13.a above. Data from these manoeuvres is presented in Annex A, Table A-1. In addition, all 12 manoeuvres flown on sortie 2 and which were associated with the bent loop evaluation described in paragraph 13. c were terminated in a rolling escape manoeuvre on completion of the apex data gathering. The assessed escape manoeuvres in sortie 1 were flown at AUMs that were 1600 - 2300 lbs heavier than G-BXFI was at impact, and those flown on sortie 2 were 750 - 2300 lbs heavier. The implication of flying these manoeuvres at a heavier weight was that the height loss during the escape manoeuvre was greater than would have been achievable by G-BXFI due to the reduction in normal acceleration available for a given airspeed. The density altitude at the apex of the accident manoeuvre was 4000 ft. During sortie 1 the apex density altitudes varied between 3000 and 3400 ft and during sortie 2 between 2400 and 3200 ft. Therefore, the maximum difference between the density altitudes at which the data gathering manoeuvres were flown and that of the accident sortie was 1500 ft. In flight test a tolerance of +/- 2000 ft is the accepted norm for the comparison of aerodynamic data such as this. Therefore, the differences in density altitude between the accident sortie and the manoeuvres flown during sorties 1 and 2 should have had no significant effect on the escape manoeuvre data collected although, theoretically, with a slighter lower TAS for a given IAS at a lower density altitude, the data gathered would indicate slightly less height lost than for the accident conditions. The maximum altitude loss measured during any of the escape manoeuvres was 2300 ft, and this was the extreme case of delaying the roll for 4 seconds past the apex by when the aircraft was 45˚ nose down. If an identical manoeuvre had been attempted in G-BXFI during the accident manoeuvre the height loss would probably have been less due to it being 1600 lbs lighter AUM than the test manoeuvre, albeit with the higher density altitude theoretically reducing this benefit slightly. With respect to aircraft handling, the manoeuvres were very straightforward and instinctive to fly for a pilot with fast jet experience, even when a speed as slow as 80 KIAS (20 KIAS slower than that during the accident manoeuvre) was achieved at the apex. The nose dropped noticeably during all of the rolls, as it would with any aircraft type flown in the same manner, because no attempt was made to maintain level flight by the use of elevator or rudder inputs. It was easy to maintain neutral rudder with just light pressure applied to both rudder pedals with no noticeable tendency for rudder float. At no stage was any lateral acceleration felt and the aircraft behaved very predictably, indicating that if the escape manoeuvre was flown in this manner there was no risk of a departure from controlled flight. Philosophically, the escape manoeuvres flown were akin to a 'roll-off-the-top' or 'Immelmann Turn' which is a standard level aerobatic manoeuvre, albeit one whereby an attempt is made to maintain level flight during the roll by the co-ordinated use of elevator and rudder. Based on the aircraft handling and height loss observed during the 18 escape manoeuvres flown during sorties 1 and 2, it would have been possible for an appropriately trained pilot easily to have flown a straightforward escape manoeuvre in G-BXFI at any time up to at least 4 seconds after reaching the apex of the accident manoeuvre and thereby to have avoided a ground collision.

c. Height Loss During Continued Looping Manoeuvre During sortie 1, seven minimum radius loops, as described in paragraph 13b, were flown with varying flap and power settings as detailed in Annex A, Table A-2. However, these were all at apex density altitudes and fuel weights that were higher than those of the accident sortie and, therefore, the data gathered indicated a greater height loss during the pull through than would have been achievable on the accident sortie. Therefore, a further five minimum radius loops were flown during sortie 3 in order to get more comparable data. The pull-up power setting for this latter sortie of 7200 RPM was determined by an attempt to achieve 100 KIAS at the apex. Although the apex airspeeds were slightly higher than that of the accident sortie, a lower power setting was considered to be unwise for safety reasons. The apex density altitudes achieved on sortie 3 had between 0 and +400 ft difference from the accident sortie, and the AUM was from 100 - 800 lbs less. The altimeter reading resolution was tightened to the nearest 50 ft for both the apex and minimum height points. During the sortie 3 manoeuvres the apex airspeeds ranged from 105 - 135 KIAS (100 KIAS in the accident manoeuvre) and the height loss from the apex to regaining level flight varied from 2700 ft to 2850 ft, with the greater height loss values being seen with the highest apex speeds. However, within the accuracy of the tests and the number of tests flown this relationship between height loss and airspeed may have been within the tolerances of how repeatably the manoeuvres could be flown by pure feel (i.e. the AOA) and, therefore, is not conclusive. The total altimeter reading plus instrument error for the sortie 3 data was ± 100 ft and, therefore, the range of height loss was theoretically between 2600 and 2950 ft. Below is a discussion of the effect of relevant factors on the height loss.

(1) Effect of Flap Four of the sortie 3 loops were flown with 1 notch of flap and one with 2 notches. There was no significant difference in the height loss during pull through between the flap angles. On sortie 1 the first 3 loops were flown with 1 notch of flap, the next 3 with 2 notches and the final one with 4 notches selected at the apex. However, the height loss data from this sortie was inconclusive with respect to flap setting due having simultaneous reducing fuel weight and increasing flap deflection. Overall, it was concluded that the height loss during the pull through was not significantly different as a function of whether 1 or 2 notches of flap were selected.

(2) Effect of Mass During the minimum radius loop manoeuvres flown on sortie 3 the AUM reduced from just 100 lbs below the estimated accident mass to 800 lbs below. The height loss during the first and last manoeuvre was the same. Therefore, the data gathered can, with respect to AUM, be considered as representative of the accident sortie.

(3) Effect of Power The effects of power on the height loss were assessed during sortie 1. All of these loops were entered with the equivalent of T Mk7 maximum thrust, and at the apex the power was varied between idle, which was less than in the accident manoeuvre, and maximum which, in the F Mk58, was greater than was available in G-BXFI. Significant differences (80 KIAS) were seen in the speed at the end of the manoeuvres as a function of power setting past the apex but power did not have any significant effect on the height loss with the exception of the final loop with 2 notches of flap when maximum power may have reduced the height loss slightly. The speeds at the top of the loops on sortie 1 were 15 - 20 KIAS greater than that of G-BXFI but the speed at the bottom bracketed that indicated just before impact (210 KIAS) as a function of power, with idle power from the apex giving 190 and 180 KIAS and maintaining the power from apex giving 260 and 230 KIAS for flaps 1 and flaps 2 respectively. These tests indicated that the height loss from apex during the accident manoeuvre was not affected significantly by power setting.

(4) Handling Qualities The buffet amplitude tended to reduce as IAS reduced. During the pull-through phase of the loops which had the lowest airspeed at the apex sometimes a slight roll-off to the right through about 10˚ with a simultaneous slight rudder float was observed. The slightest reduction in the pull force on the stick at that point reduced the angle of attack sufficiently for these characteristics to cease; it was then easy rapidly to regain the desired level of buffet for continuing a maximum performance pull-out. This demonstrated that at representative airspeeds, weights and altitudes there were cues to the pilot of when he had reached the maximum instantaneous turn performance of the aircraft, and overall the aircraft was easy to handle in this high angle of attack regime.

To conclude, the measured height loss during a representative pull through was between 2700 and 2850 ft, and if altimeter reading and instrument errors were considered the range would increase to between 2600 and 2950 ft. The height loss appeared to be insensitive to whether 1 or 2 notches of flap were selected and to the power setting.

d. Apex Height and Airspeed in a 'Bent Loop' For consistency, all of these manoeuvres were flown with the same flap setting (1 notch). All were flown in the same level of buffet throughout the pull up which aimed to achieve the optimum lift from the wings and thus the minimum radius. Back-to-back comparisons between straight pulls, 45˚ bends and 90˚ bends were flown whenever possible to minimise the effects of fuel consumption and reducing AUM. Power was progressively reduced between each test point in order to attempt to achieve the apex speed of the accident manoeuvre. However, reductions below 7000 RPM (400 RPM below that required for equivalence in thrust to full power in a T Mk7 and 100 RPM greater than that for thrust equivalence with the accident manoeuvre RPM at pull-up) were not made for safety reasons due to the low IAS being reached at the apex of the straight pull-ups. The data from these tests are presented in Annex A, Table A-3. The height at the apex of a 45˚ or 90˚ bent loop was consistently 300 - 400 ft less than that of a straight half loop flown at essentially the same weight. Commensurately, the IAS was 20 - 30 KIAS greater at the apex of the bent loops (albeit with one comparison being 45 KIAS greater from a 90˚ bend). In absolute terms, the final 45˚ bent loop manoeuvre flown reached an apex height of 2800 ft and a speed of 120 KIAS. The aircraft weight for this manoeuvre was 750 lbs greater than for the accident manoeuvre (which would result in a higher apex height if flown at the same AOA) and therefore the apex parameters seen appeared to be consistent with those achieved in the accident manoeuvre (2700 ft and 100 KIAS). The fact that the speed achieved during the test sortie was 20 KIAS higher than in the accident sortie indicated that the accident manoeuvre was probably flown with a lower mean thrust setting than that of this test manoeuvre; this supposition is supported by the RPM spectrum analysis data. In addition, the minimum radius loop tests (see paragraph 15. c(3) above) showed that power had little measurable effect on looping radius during the downward portion when flown with an AOA for maximum usable lift and so the small amount of extra thrust used during these tests should not have affected the apex heights significantly. The test data showed consistently that any 'bend' during the first half of a loop would reduce the apex height. It is worthy of note that the minimum radius straight loop data from sorties 1 and 3 showed a height gain from pull-up to completion of 300 - 500 ft. The bent loop data showed a reduction in apex height of a similar amount, implying that if a maximum performance pull through in light buffet was not flown there was a strong possibility that the height at completion of a bent loop could be less than the pull-up height. One aspect that was difficult to reproduce was the impact upon the apex height of the precise pitch attitude at commencement of the roll. In the loops flown, the rolls were commenced at 5 seconds after pull up which was based on what was estimated from the cockpit video evidence of the accident flight. This equated to an estimated 80˚ nose up pitch attitude on the data gathering flights. If on the accident flight the nose up pitch attitude when the roll was initiated was any less than this, as some external video recordings appear to show, then geometrically the apex height should have been lower. However, to achieve a lower pitch attitude in the same time (5 secs) would have required a reduced pitch rate which would have resulted in a greater apex height; therefore there would have been compensating variations and probably little overall difference in apex height as a function of a slightly different technique. Overall, the data gathered during the bent loop tests indicated that the apex height and airspeed of the accident manoeuvre were consistent with a maximum performance pull-up from 300 KIAS with significantly less than full thrust and with a 45-90˚ bend initiated approximately 5 seconds after pull-up It also showed that the apex height for a 'bent' loop was 300 - 400 ft less than for a straight loop with all other parameters maintained constant..

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e. Nominal Entry Parameter 'Bent' Loop These were flown as detailed in paragraph 13.d at an AUM of 1500 - 1600 lbs greater than that of G-BXFI when the accident occurred. The manoeuvre flown with 1 notch of flap had apex conditions of 5250 ft and 170 KIAS. The one flown with 2 notches of flap achieved 5750 ft and 155 KIAS at the apex (altimeter heights with QFE set). These manoeuvres were very comfortable and straightforward to fly, and the variability in apex height was probably due to applying slightly different normal accelerations and pitch rates through the pull-up. During the last quarter of the loop the g was reduced in order to make a smooth capture of the 500 ft base height. The apex heights had a significant margin above what would normally be used as a gate height, and the apex speeds achieved were high enough to give a very comfortable margin above the stall. Due to delaying selection of the flaps until the speed had reduced to the 300 KIAS limit, the aircraft had slightly less drag during the pull-ups as flown compared to that for one flown with flaps set throughout. Therefore, the speed at apex would have been slightly higher as flown compared to using flaps throughout. However, this extra flap drag should not have reduced the speed by an amount that would cause any problems whatsoever. A 90˚ 'bent' loop entered at 350 KIAS with full T Mk7 thrust was, for an appropriately trained pilot, a safe and straightforward manoeuvre to fly.

16. Conclusions Based on the data gathered during the sorties flown in Hunter F Mk58 ZZ190, the following conclusions can be drawn:

a. The analysis indicates that there is no significant difference in maximum instantaneous turn performance between a Hunter T Mk7 and F Mk58 and the lift related data gathered in the F Mk58 is representative of that of a T Mk7.

b. From the apex height and airspeed achieved in the accident manoeuvre, and for up to at least 4 seconds after passing the apex, it would have been possible for an appropriately trained pilot to fly a straightforward escape manoeuvre in G-BXFI which would have prevented impact with the ground by rolling the aircraft through 180˚ back to erect flight and then pulling out of the dive to regain level flight

c. The measured height loss during a representative pull through from the apex of a loop at the airspeed, all up mass and density altitude of the accident manoeuvre was between 2700 and 2850 ft, and if altimeter reading and instrument errors were considered the range would increase to between 2600 and 2950 ft. The height loss appeared to be insensitive to whether 1 or 2 notches of flap were selected and to the power setting.

d. The 'bent' loop tests indicated that the apex height and airspeed of the accident manoeuvre was consistent with a maximum performance pull-up from 300 KIAS with significantly less than full thrust and with a 45-90˚ bend initiated approximately 5 seconds after pull-up They also showed that the apex height for a 'bent' loop was 300 - 400 ft less than for a straight loop when all of the other parameters remained constant.

e. A 90˚ 'bent' loop entered at 350 KIAS with full T Mk7 thrust was, for an appropriately trained pilot , a safe and straightforward manoeuvre to fly.

Annex A to
Report on G-BXFI Accident

Serial	Flaps (notches) (1)	Manoeuvre Flown (2)	Power	Apex Height (ft QFE)	Minimum height during recovery (ft QFE)	Height loss during escape manoeuvre - Apex to minimum (ft)	Apex IAS (kts)	IAS at minimum height during recovery (kts)	All Up Mass (lbs)	Difference in AUM from G-BXFI (lbs) (3)	Difference in apex density altitude from G-BXFI (ft) (4)
1	1	Roll when nose on horizon	Maintained throughout	3600	2500	1100	110	220	19 900	+2300	-800
2	1	Roll when nose on horizon	Idle at apex	3800	2500	1300	120	175	19 700	+2100	-600
3	2	Roll when nose on horizon	Maintained throughout	3700	2600	1100	120	210	19 600	+2000	-700
4	2	Roll when nose on horizon	Idle at apex	3400	2200	1200	110	170	19 500	+1900	-1000
5	2	Roll when nose 30˚ nose down	Idle at apex	3600	1600	2000	120	190	19 400	+1800	-800
6	2	Roll when 45˚ nose down (4 secs past apex)	Idle at apex	3500	1200	2300	110	200	19 200	+1600	-900

Notes:
1. 1 notch of flap was 16˚, 2 notches was 23˚.
2. Entry/pull up from 300 KIAS, 200 ft QFE, 7400 RPM (T Mk7 maximum thrust equivalent).
3. Rounded down to nearest 100 lbs.
4. Quoted figures rounded down to nearest 100 ft.

Table A-1. Sortie 1: Escape Manoeuvre Data

A-1

Appendix H (Cont)

Serial	Flaps (notches) (1)	Pull Up Parameters	Power	Apex Height (ft QFE)	Minimum height at end of pull through (ft QFE)	Height loss during pull through - Apex to minimum (ft)	Apex IAS (kts)	IAS at minimum height during recovery (kts)	All Up Mass (lbs)	Difference in AUM from G-BXFI (lbs) (3)	Difference in apex density altitude from G-BXFI (ft) (4)
SORTIE 1											
7	1	300 KIAS, 7400 RPM, 2000 ft QFE	Maintained throughout	5600	2300	3300	115	260	19 100	+1500	+1200
8	1		Idle at apex	5600	2400	3200	115	190	18 900	+1300	+1200
9	1		Max at apex	5500	2300	3200	120	270	18 800	+1200	+1100
10	2		Maintained throughout	5500	2500	3000	120	230	18 750	+1100	+1100
11	2		Idle at apex	5500	2400	3100	120	180	18 200	+600	+1100
12	2		Max at apex	5200	2400	2800	115	260	18 050	+400	+800
13	2 with 4 selected at apex		Maintained throughout	5300	2400	2900	125	230	17 750	0	+900
SORTIE 3											
14	1	310 KIAS, 7200 RPM, 1500 ft QFE	Nominal 6600 RPM selected at apex	4550	1850	2700	115	200	17 500	-100	0
15	1	300 KIAS, 7200 RPM, 1500 ft QFE		4750	1900	2850	135	220	17 300	-300	+200
16	1			4500	1750	2750	105	190	17 100	-500	0
17	2			4600	1800	2800	135	230	16 950	-600	+100
18 (5)	1			4950	2250	2700	110	220	16 800	-800	+400

Notes:

1. 1 notch of flap was 16˚, 2 notches was 23˚, 4 notches was 38˚.
2. Max power was full F Mk58 thrust.
3. Rounded down to nearest 100 lbs.
4. Quoted figures rounded down to nearest 100 ft.
5. g was reduced before apex to reduce IAS at apex.

Table A-2. Sorties 1 and 3: Minimum Radius Loop Data

A-2

Appendices

Appendix H (Cont)

Serial	Manoeuvre (1)	Pull-Up Parameters (QFE height)	Pull-up Power (RPM)	Apex Height (ft QFE)	Height increase pull-up to apex (ft)	Apex IAS (kts)	All Up Mass (lbs)	Difference in AUM from G-BXFI (lbs) (2)	Difference in apex density altitude from G-BXFI (ft) (3)
19	Straight pull-up	200 ft, 300 KIAS	7400	3700	3500	115	19 900	+2300	-600
20	90˚ bend	200 ft, 300 KIAS	7400	3400	3200	135	19 800	+2200	-900
21	Straight pull up	200 ft, 290 KIAS	7000	3600	3400	80	19 600	+2000	-700
22	Straight pull up	200 ft, 290 KIAS	7200	3600	3400	90	19 500	+1900	-700
23	90˚ bend	150 ft, 290 KIAS	7200	3200	3050	135	19 400	+1800	-1100
24	Straight pull-up	150 ft, 300 KIAS	7000	3300	3150	90	19 300	+1700	-1000
25	90˚ bend	250 ft, 300 KIAS	7000	3000	2750	110	19 200	+1600	-1300
26	45˚ bend	200 ft, 300 KIAS	7000	3000	2800	110	19 000	+1400	-1300
27	Slightly less than 45˚ bend	100 ft, 300 KIAS	7000	3300	3200	100	18 800	+1200	-1000
28	45˚ bend	100 ft, 300 KIAS	7000	2800	2700	110	18 600	+1000	-1500
29	Straight pull-up	100 ft, 290 KIAS	7000	3200	3100	90	18 400	+800	-1100
30	45˚ bend	100 ft, 290 KIAS	7000	2800	2700	120	18350	+700	-1500

Notes:
1. All manoeuvres flown with 1 notch (16˚) of flap.
2. Rounded down to nearest 100 lbs.
3. Quoted figures rounded down to nearest 100 ft.

Table A-3. Sortie 2: Bent Loop Data

A-3

Appendix J

Review of the 2015 Shoreham Airshow Air Display Risk Assessment

HEALTH & SAFETY LABORATORY

Review of the 2015 Shoreham Airshow Air Display Risk Assessment

February 2016
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Harpur Hill, Buxton
Derbyshire, SK17 9JN
T: +44 (0)1298 218000
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REVIEW OF THE 2015 SHOREHAM AIRSHOW AIR DISPLAY RISK ASSESSMENT

MSU/2016/04

Report Approved for Issue by:	
Date of Issue:	**25 February 2016**
Lead Author:	
HSL Project Manager	
Technical Reviewer(s):	
Editorial Reviewer:	
HSL Project Number:	**PE06406**

Production of this report and the work it describes were undertaken under a contract with the Air Accident Investigations Branch (AAIB). Its contents, including any opinions and/or conclusion expressed or recommendations made, do not necessarily reflect policy or views of the Health and Safety Executive.

Appendices

Appendix J (Cont)

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HEALTH AND SAFETY LABORATORY
Review of the 2015 Shoreham Airshow Air Display Risk Assessment, MSU/2016/04

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Appendices

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SUMMARY

The Air Accident Investigation Branch (AAIB) asked the Health and Safety Laboratory (HSL) to assess the 2015 Air Display Risk Assessment for the Shoreham Airshow in 2015. A crash leading to multiple fatalities occurred at the airshow and the AAIB would like to know whether the risk assessment undertaken prior to the show was fit for purpose.

HSL is the science laboratory for the Health and Safety Executive (HSE). HSL provides scientific evidence to support HSE policy and regulation and provides expertise and advice for businesses both within the UK and internationally. The HSL risk assessment specialists therefore have extensive experience in assessing hazard and risk assessments from a regulatory Health and Safety perspective.

HSL reviewed the 2015 Shoreham Air Display Risk Assessment to ascertain whether it was suitable, sufficient and fit for the purpose of ensuring that the risks for the air display had been fully considered and were being managed appropriately. The equivalent 2013 and 2014 Air Display Risk Assessments were used to assess how the risk profiles for the show had been developed over time. The Royal Air Forces Association (RAFA) Battle of Britain Air Show Shoreham Airport Risk Assessment, which is essentially a ground risk assessment, for 2015 was also considered within this review process. The guidance for air displays given by the Civil Aviation Authority (CAA) was also considered within the review, as was HSE guidance on risk assessment and other literature on risk assessment and risk management.

It was found that the Shoreham Airshow Air Display Risk Assessment contained a number of deficiencies compared to what would be expected for a risk assessment to control risks to the public. There is little, or no, evidence that:

- all relevant parties were consulted in the assessment of the hazards and risks,
- a comprehensive list of foreseeable hazards was identified,
- sufficient and achievable mitigation measures were considered and implemented,
- lessons were learned from near misses or incidents at previous airshows (either previous Shoreham airshows or other airshows).

There is no demonstration that the hazards and risks identified have been managed sufficiently, e.g. evidence of implementation of mitigation controls, re-assessing risks to ascertain impact of mitigation, etc.

The risk assessment does not fully comply with the CAA guidance for air displays. Compliance with the industry guidance would be expected as a minimum.

It is not clear that those who assessed the risks and recorded the assessment had a full understanding of the purpose of the risk assessment.

There is no evidence that a review process was undertaken. Although additional information has been obtained by the AAIB that indicates some form of review was undertaken, it is not clear who was consulted and it was not recorded in the risk assessment. It is not clear whether there was a proper sign-off of the Risk Assessment due to the use of a digital signature, especially where there are contradictory dates for the assessment document with the sign-off date.

The conclusion of the review is that the 2015 Shoreham Airshow Air Display Risk Assessment is not fit for the purpose of identifying and mitigating the risks and hazards to the public from the air display activities of the airshow.

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1 INTRODUCTION

At the Shoreham Airshow on 22 August 2015 a vintage jet aircraft crashed onto a nearby road, killing 11 people and injuring 16 others. The pilot was amongst those injured in the accident. The Air Accident Investigation Branch (AAIB) is undertaking the accident investigation to determine the causes of the accident and identify recommendations to avoid any similar occurrences in the future.

The AAIB asked the Health and Safety Laboratory (HSL) to assess the 2015 Air Display Risk Assessment for the Shoreham Airshow in 2015 [1]. As part of the Health and Safety Executive (HSE), HSL provides scientific advice on health and safety matters to the UK government and to businesses in the UK and internationally. The HSL risk assessment specialists have experience of reviewing hazard and risk assessments from a regulatory perspective across a range of industries and activities.

The AAIB provided HSL with the Shoreham Air Display Risk Assessment for the 2015 airshow [1], together with the corresponding assessments for 2014 [2] and 2013 [3].The AAIB also provided the RAFA (Royal Air Forces Association) Battle of Britain Air Show Shoreham Airport Risk Assessment [5], which is a ground risk assessment for the 2015 airshow.

HSL reviewed the 2015 Air Display Risk Assessment in relation to the guidance for flying displays and special events published by the Civil Aviation Authority (CAA) [4]. The risk assessment was compared with the guidance given in the HSE publication “Reducing Risks, Protecting People” [6], together with other published guidance [7, 8] and health and safety legislation [9].

The remainder of the report is structured as follows:

- Section 2 presents the findings of the review and the comparison with the RAFA Battle of Britain Air Show Shoreham Airport Risk Assessment [5], the various guidance documents and the legislation; and

- Section 3 presents the conclusions from the review.

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2 REVIEW OF THE 2015 AIR DISPLAY RISK ASSESSMENT

2.1 OVERVIEW OF THE STRUCTURE OF THE RISK ASSESSMENT

The Air Display Risk Assessment for the 2015 Shoreham Airshow has followed the same structure as the assessments undertaken for the 2013 and 2014 Shoreham Airshows.

The version of the 2015 assessment provided to HSL states that it is a draft assessment. The AAIB has confirmed that a final version of the risk assessment has not been made available to the AAIB. It is unclear if the 2015 assessment was ever finalised, or whether the document provided is the final version that is incorrectly described as a draft. The lack of clarity over a final version of the risk assessment indicates a deficiency in the record keeping in the risk assessment process.

The document reviewed and discussed in this section is therefore the Draft 2015 Air Display Risk Assessment for the Shoreham Airshow that has been obtained by the AAIB.

Within the Air Display Risk Assessment, there is a description of the roles of key people throughout the duration of the airshow. These are:

- The Flying Display Director (FDD) who has overall responsibility for “Air Display Flight Safety” under the Civil Aviation Authority (CAA) permissions. The FDD is responsible for developing and maintaining a “Flight Safety culture” throughout all aspects of the flying display operation;
- The Flying Control Committee (FCC) who have specific safety oversight of the flying display operations;
- The Chair of the FCC (CFCC) who has “the authority to make over-riding operational and flight safety decisions on any part of the Flying Display”.

The risk assessment does not provide the qualifications for the FDD but states that the CFCC and FCC are chosen because of their “wealth of flying experience in general and display related experience in particular”. The risk assessment states that the FDD and CFCC must ensure that members of the FCC are present throughout the display flying periods. In addition, part of the FDD, CFCC and FCC duties includes contacting the pilots directly by radio during displays, should the need arise. This is for the sole purpose of terminating a display in progress for safety reasons.

The purpose of the risk assessment is discussed within the Shoreham Airshow Air Display Risk Assessment document. Safety assessment criteria are described and the risk matrix used to assess the risks is outlined. Tables are provided for each hazard that has been identified and considered. These tables include:

- a description of each hazard;
- the risk of the hazard identified by use of the risk matrix;
- what mitigation can be considered;
- the appropriate actions to take and by whom for each mitigation method.

Each row of the table is signed by the Flying Display Director (FDD).

A final table is provided in the Air Display Risk Assessment summarising each hazard, the risk of the hazard on the risk matrix and the impact of the risk mitigation methods identified. A statement is made at the end of the report stating that all risks are now "Acceptable".

The Air Display Risk Assessment does not cover normal airport licensed operations (e.g. take-offs and landings) as these are covered under the Shoreham Airport risk assessment.

2.2 GENERAL COMMENTS

2.2.1 Comparison with previous risk assessments

The comparison of the 2015 Air Display Risk Assessment with those from 2013 and 2014 revealed that only minor modifications had been made to two of the hazards assessed when compared to the 2014 Air Display Risk Assessment. It was also noted that the date that each of the hazards had been signed off on was the same for 2015 and 2014, with just the year itself changed. In the 2015 assessment the date for the sign-off for each hazard is given as 14 August 2015, but the assessment itself is dated 6 April 2015. The date for the 2014 assessment document is given as 14 August 2014. The signature used for the sign-off appears to be scanned in, and so there is no indication that the assessment was seen by the person whose signature appears on the form.

The concern from these points identified is that there appears to have been no proper review of the hazards and risks undertaken in 2015. It looks like the previous year's assessment was reused with only the minor amendments and the change of dates. It is possible that the assessment was not even signed off by the Flying Display Director (FDD), with the previous year's signatures used to authorise the assessment. Even if these anomalies are just typographical errors, it does not give confidence in the quality of the assessment and the acceptance criteria used in the sign-off of the document.

The AAIB has obtained information that indicates that the FDD, who signed off the risk assessment, did see the document and passed it to others for comment. This is not made clear from the risk assessment itself and it is not clear who else has seen the risk assessment.

As there is no obvious final version of the risk assessment, there does not appear to be a final sign-off prior to the Shoreham Airshow.

There is nothing within the preliminary sections of the Air Display Risk Assessment that states when and how the risk assessment was reviewed. Section 2.1.4 does state that the "Airshow Management of Safety is subject to routine review" but it is not stated how often this occurs. This section of the assessment also states that "the introduction of new RA [Risk Assessment] and associated Actions Required and the progress of existing Actions Required will be reviewed for each Flying Display and during informal meetings between RAFA [Royal Air Forces Association], CAA, the Airport Operator and Air Traffic Control". There is no record if and when this process has occurred for this assessment.

Information obtained by the AAIB indicates that the risk assessment was reviewed annually prior to the event. It is not made clear how this review was undertaken, and who contributed to the review. It appears that issues highlighted by other people consulted as part of the review process have not been properly incorporated within the risk assessment. For example, in this review process, SATCO (Senior Air Traffic Control Officer) highlighted that the majority of the crowd line is not visible from the VCR (Visual Control Room); however, the final risk assessment still lists Air Traffic Control observing the crowd barrier line as a mitigation measure to reduce the risk. The risk assessment should have been updated to reflect the concerns raised by SATCO that this measure was not a practical way of reducing this risk. This indicates an incomplete or insufficient review process. There is no record of this process within the risk assessment.

It is not obvious from the risk assessment document that the risk assessment has been reviewed or even seen by the appropriate people (e.g. the FDD, the FCC, pilots, etc.), although additional information obtained by the AAIB indicates that some form of review has occurred. No record is made that the indicated review process did take place. The only signature in the assessment document is that of the FDD which, as has already been stated, appears to be a digitally scanned-in signature.

There is no evidence that any process has been undertaken to determine if the identified hazards are still appropriate, or if there are any additional mitigation methods that could be considered. It appears that even in the review process that was undertaken that issues that were identified with some of the hazards and mitigation measures have not been implemented in the risk assessment. It is not clear that there has been any thought given to the impact of changes in the layout and running of the show which may or may not have occurred in the intervening years.

2.2.2 Comparison with the Shoreham Airshow ground risk assessment

The RAFA Battle of Britain Air Show Shoreham Airport Risk Assessment covers events that are occurring on the ground, from issues with the car parks to accidents in the children's areas to possible fires in marquees and food stalls. This document has not been reviewed but the structure of the assessment and the process undertaken has been compared with the Air Display Risk Assessment.

The main difference between the two risk assessments is in the structure of the risk matrix and how it is used. The ground risk assessment more closely follows the guidance given in CAP 403 [4]. The RAFA Battle of Britain Air Show Shoreham Airport Risk Assessment lists:

- the activity;
- the hazard associated with the activity;
- the people that could be affected by the hazard;
- the severity of the consequences if the hazard were to occur;
- the likelihood of the hazard occurring and affecting a person;
- the consequent risk rating on the risk matrix;
- the actions that can be taken to lower the risk;
- the effect of the actions on the likelihood and/or severity of the consequences; and
- the final level of risk following the implementation of the mitigation and controls.

The Air Display Risk Assessment, in contrast, does not separate the hazard from the activity, and it does not directly state who is at risk. The Air Display Risk Assessment does not show the impact of any mitigation measures on the severity or likelihood. The conclusion of the Air Display Risk Assessment is that the risks have all been reduced to "Acceptable", the lowest risk ranking, with no link made to how the mitigation and control measures affect the final risk rating.

2.2.3 General points

No map is included with the risk assessment. The inclusion of a map of the show area would aid with the identification of the areas that could be affected by the hazards. This would indicate population areas, where the spectators are expected to be, nearby population centres, and neighbouring roads, etc. This visual aid would be beneficial to those involved in the assessment process, and to those involved with the show who may not be familiar with the layout of the area. It would also aid in highlighting areas that have changed since the previous year's airshow.

In Section 2.1.1 of the Air Display Risk Assessment, four questions are asked, the first of which is "Does an actual or potential hazard to Airport/ATS [Air Traffic Services] operational safety exist in this area of operation?". The emphasis of the question may cause confusion in the assessment of the risks. The purpose of the risk assessment is to assess the risk of people being harmed by the operations of Shoreham Airshow. Therefore, it might be more beneficial to explicitly state this purpose, especially as an airshow is likely to have a different demographic of people located in different areas than for normal airport operations.

2.2.4 Hazard identification

When carrying out a risk assessment, a process needs to be undertaken to identify the hazards associated with the activity, in this case, the hazards from aircraft displays. This is often referred to as a hazard identification process and can take the form of a "brain-storming" session, where experts in the field use their knowledge to identify a number of hazards. Some of the hazards identified in this way may later be discarded, provided valid reasoning is given (e.g. the hazard is found not to be credible given the type of aircraft at the airshow).

It is normal good practice to provide some record of this process. This would include the people who performed the hazard identification, their qualifications and experience, and a list of the hazards identified. The reasons for discounting some of these identified hazards would also be given. For an event such as an airshow, it would be expected that representatives from the airfield, pilots, the FDD, members of the FCC and other parties directly concerned with the safety of the event would be involved in the hazard identification process.

In the Shoreham Airshow Air Display Risk Assessment for 2015, no information is provided as to how the hazards considered in the assessment were identified, or who was involved in the Hazard Identification process. This means that it is not possible to state whether or not a comprehensive process was undertaken and whether the hazards identified are exhaustive.

HSL has quickly identified additional hazards that have not been considered in the risk assessment (e.g. mechanical failure of the aircraft, the effects of the pilot becoming incapacitated, detachable parts of the plane falling into the crowd, aircraft crash within the airfield boundary and so on). Each of these hazards could have catastrophic consequences and should have been considered in the assessment.

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The hazards considered in the risk assessment are:

1. Airside unauthorised access;
2. Mid-air collision – display and non-display aircraft;
3. Mid-air collision – display formation;
4. Ejector seat impacts crowd;
5. Loss of control due to pilot disorientation;
6. Location of built up areas;
7. Public assembly on A27 and local roads;
8. Aircraft crash outside the airfield boundary;
9. Fast jet aircraft collision into crowd area; and
10. Fatigue amongst key safety staff.

Hazards number 6 and 7 are potentially misleading and are not hazards as described. It is the consequences of an aircraft crashing in these areas that is the actual hazard. The lack of clarity could lead to confusion regarding exactly what is being assessed. This will be discussed in more detail in subsequent sections.

There is no record that the list of hazards has been reviewed to ascertain whether or not they are still suitable and sufficient for the purposes of the risk assessment. Any changes to the operation of the airshow, or to the type of aircraft flying at the airshow could affect the list of identified hazards.

Additional information obtained by the AAIB indicates that the first risk assessment, including the identified hazards, was written in 2013 and circulated for comments, allowing people to suggest additional hazards. However, there is no record that these people were directly involved in the hazard identification process.

The risk assessment was circulated again in 2014 and 2015 for comment. There is no record in the risk assessment itself that any of these reviews occurred. One of the responses from circulating the risk assessment identified that there are civil aircraft that could lead to hazard 4 (ejector seat impacts crowd). In the risk assessment, the mitigation measures are only applied to military aircraft. No modification to the text in the risk assessment was made as a result of the comment made by one of the reviewers. At the least, the risk assessment should have identified that this observation had been raised and given a justification for not incorporating this into the risk assessment.

There is no recorded process for identifying mitigation measures for each of the identified hazards. Only those that are being implemented are discussed in the risk assessment. It could be expected that additional measures were identified, which may have been dismissed for legitimate reasons. There is, however, no record that any additional measures have been considered, or that any systematic process was undertaken to identify potential mitigation measures or actions.

It is possible that a full hazard identification process was undertaken and recorded elsewhere. No reference is made to such a document from the risk assessment, however, and none has been made available to HSL.

In summary, there is no evidence that a suitable hazard identification process was undertaken and it appears that not all plausible hazards have been considered. In addition, there appears to have been no clear process for identifying mitigation measures, and then determining which could and should be implemented.

2.2.5 Review process

A risk assessment should be reviewed regularly to ensure that it is still valid for the processes/events being assessed and a record made that a review has been undertaken. Even if no changes have been identified, a statement to this effect should be included. In the Shoreham Airshow Air Display Risk Assessment there is no process described for updating and reviewing the risk assessment, other than very general statements in Section 2.1.4 of the assessment. These statements have already been discussed in Section 2.2.1 of this report. There is no statement made that a review was undertaken prior to the 2015 airshow. There are some minor modifications to the text for two of the hazards assessed, which are in revision mode and appear to be incomplete. Given the other issues identified, which are discussed subsequently, such as the misclassification of risks which has been there since at least 2013, then it seems likely that there has not been a proper review of the risk assessment. More significant changes would be expected for an annual event where each year should increase the knowledge of managing the safety at the event.

The AAIB have obtained additional information that indicates the risk assessments for 2013, 2014 and 2015 were sent to other people for comments. It appears that this was done by email with no record of any meetings to fully discuss the risk assessment. There is no record of the review process in the risk assessment. It is also not clear who was involved in the review process in the risk assessment document. Some of the comments made by the reviewers do not appear to have been fully incorporated within the risk assessment (e.g. the identification of civil aircraft that could cause hazard 4, but the mitigation measures only being applied to military aircraft).

It would be expected that at a dynamic event such as an airshow, lessons would be learnt each year from issues that arise. These can be from issues that occurred and had to be resolved during the airshow, and also from processes that were particularly effective at managing the risks. This allows an assessment to be made as to whether measures in place are working effectively, and whether they can be applied to other aspects of the show, or whether problems have arisen which require additional measures to enhance the safety. Anything identified in this manner would be expected to be added to the risk assessment to improve safety both during the event and also for subsequent events. Even incidents that do not lead to any serious issues (near misses) can provide useful lessons for future risk management of an activity. The risk assessment should be updated to reflect lessons learnt at each airshow. There is no indication that any such process has been undertaken.

Lessons can also be learnt from incidents that have occurred at similar events (e.g. other airshows). No mention is made of this in the document.

A quick internet search has identified aircraft crashes in previous years at Shoreham Airshow [10, 11] and that there was a fatal crash at CarFest North [12] in the weeks leading up to the 2015 show. These do not appear to have been considered in the risk assessment, even if only to reassure the organisers of the Shoreham Airshow that such events could not occur during the Shoreham Air Display in 2015.

A statement is made in Section 2.1.3 of the Shoreham Airshow Air Display Risk Assessment that all personnel should "appreciate the need to take a proactive approach towards the identification of potential risk situations throughout the Flying Display period". It is not stated how or if any of this information should be recorded, however.

An additional point on the review process pertains to the CAA document, CAP 403 [4], which provides guidance for flying displays. It is stated in CAP 403 that the document was completely rewritten for the latest version, which is dated February 2015. HSL has not compared the latest version with the previous version so it is not clear how the guidance has changed, if at all. As part of the risk assessment review process, however, it should be ascertained whether any changes have been made to the guidance and to incorporate them within the risk assessment, if necessary.

If no changes have been made to the CAP 403 guidance or there are no changes that are applicable to the Shoreham Airshow, a sentence should be included in the risk assessment to outline that this guidance has been considered. No such statement has been made in the Shoreham Airshow Air Display Risk Assessment.

In summary, there is no evidence in the risk assessment that the Shoreham Airshow Air Display Risk Assessment has been suitably reviewed since the 2014 risk assessment.

2.2.6 The risk matrix

The purpose of a risk matrix is to identify a level of risk (either quantitatively or qualitatively) associated with a particular hazard. From this, the degree of mitigation required to lower the risk can be identified. The higher the risk, the greater the consideration required to be given to identifying and implementing potential risk reduction measures. This is discussed in more detail in Section 2.4.

Paragraph 3.3.2 of the Shoreham Airshow Air Display Risk Assessment states "Should a risk be calculated that produces an acceptable (A) level then the activity may be continued without further reference". This contradicts the guidance in CAP 403, which states that "Mitigation action should be taken whenever possible to reduce risk ratings even when the risk is low", and also contradicts standard risk assessment practice. It is expected that mitigation measures will still be considered for events with a low level of associated risk, but that the measures taken will be proportionate to the level of risk posed. In other words, inexpensive and easy to implement (practicable) mitigation measures would still be expected to be applied when the risk is low.

It is stated in paragraph 3.3.3 of the Shoreham Airshow Air Display Risk Assessment that "Should the risk be deemed unacceptable (U) positive actions must be carried out to reduce the risk to an acceptable level before the activity is undertaken". Standard risk assessment practice states that the risk should be lowered ALARP (As Low As Reasonably Practicable) which does not mean that it must be reduced to the "Acceptable" level, in the terminology of the Shoreham Airshow Air Display Risk Assessment. It is recognised that it is not always possible to reduce the risk into this region but that people are prepared to tolerate the risks, given the benefits accrued from an operation/process/event (i.e. in the case of the Shoreham Airshow, people tolerate a certain level of risk for the benefit of seeing air displays). CAP 403 states that unacceptable risks should be reduced to medium or low risk (i.e. not necessarily the "Acceptable" region, as used in the Shoreham Airshow Air Display Risk Assessment).

Paragraph 3.3.4 of the risk assessment states "Should the risk be determined to require review (R) then this review must be undertaken at the earliest opportunity in an effort to reduce the risk to an acceptable level". This is not what is required by standard risk assessment guidance. The review should aim to reduce the risk ALARP, which may mean that it ends up in the same risk level category, but either or both the consequences and the likelihoods have been reduced. The terminology used in the risk matrix is perhaps confusing. A more standard phrase for the "Review" region would be "Tolerable" or "Tolerable if ALARP".

It is possible that the "acceptable level" in paragraphs 3.3.3 and 3.3.4 of the Shoreham Airshow Air Display Risk Assessment does not actually mean the "Acceptable" band in the risk matrix. The phrase used leads to this inference, however, and the subsequent reduction of all the risks to "Acceptable" would imply that this is how it has been interpreted by those performing the risk assessment.

Table 1 in the risk assessment (replicated as Table 1 in this document) defines the severity classifications for the consequences. They are given as "Catastrophic", "Hazardous", "Major", "Minor" and "Negligible".

Table 1 Replication of Table 1 from the 2015 Shoreham Air Display Risk Assessment [2] showing the consequence category definitions

Classification	Catastrophic	Hazardous	Major	Minor	Negligible
Results in one or more of the following effects	Total loss of one or more aircraft and/or multiple fatalities as a result of an aircraft incident during the Shoreham RAFA Air Display 2015 that may or may not lead to Display Cancellation	Major aircraft damage and/or a single fatality that may or may not lead to a prolonged or permanent suspension of the Flying Display	Serious aircraft incident leading to the temporary suspension of the Flying Display	Minor aircraft incident that could result in interruption to the Flying Display	No effect on Shoreham RAFA Air Display 2015

The wording is different from that given in CAP 403 and the emphasis in the description of each has been changed from injury/death of people to damage to aircraft or the impact on the airshow. In this case, this appears to be misguided. There may be occasions where there are legitimate reasons to assess the risk of damage to aircraft or the impact on the airshow, but this risk assessment should be assessing hazards and risks where there could be adverse effects to people. This assessment should not be explicitly concerned with damage to aircraft or other inanimate object (unless this is then directly linked to the consequence to people, whether pilots or members of the public). It should not be explicitly concerned with whether the airshow, or a particular display, has to be cancelled.

Even though the catastrophic and hazardous classifications do refer to the consequences to people as well as aircraft, the major, minor and negligible categories do not refer to people at all. This is a serious and worrying deficiency in the risk matrix. Even if the intentions were to relate these categories to the effects on people, by not explicitly stating this in the consequence categories there could be an unconscious bias upon those assessing the hazards and risks to concentrate upon aircraft impacts rather than the health and safety of people.

Table 2 in the Shoreham Airshow Air Display Risk Assessment (replicated as Table 2 in this document) lists the likelihood categories in the risk matrix and provides a qualitative definition of them. They are given as "Extremely improbable", "Improbable", "Remote", "Occasional" and "Frequent". The table also has a section described as a quantitative definition, in which it is stated "Definition not required as the Flying Display programme is regulated to one aircraft or one formation displaying at any time". It is not clear what this statement is trying to say and appears to have no relevance to the table. It does not provide justification for not providing a quantitative assessment. A quantitative assessment may not be possible as there may be insufficient data available to provide any quantitative information, in which case a statement should be made to this effect.

Table 2 Replication of Table 2 from the 2015 Shoreham Air Display Risk Assessment [2] showing the likelihood definitions

Classification	Frequent	Occasional	Remote	Improbable	Extremely Improbable
Qualitative definition	Likely to occur many times during the Shoreham RAFA Air Display 2015	Likely to occur sometime during the Shoreham RAFA Air Display 2015	Unlikely but possible to occur during the Shoreham RAFA Air Display 2015	Very unlikely to occur during the Shoreham RAFA Air Display 2015	Almost inconceivable event will occur during the Shoreham RAFA Air Display 2015
Quantitative definition	Definition not required as the Flying Display programme is regulated to one aircraft or one formation displaying at any time.				

The risk matrix is presented in Table 3 of the risk assessment (replicated as Table 3) where each cell is labelled as "Unacceptable", "Review" or "Acceptable". This differs from the matrix provided in CAP 403 [4] where numbers are assigned to each consequence and likelihood category. The numbers are multiplied together, leading to different numbers in each cell of the matrix. Risk reduction measures reduce the consequence or likelihood number, which in turn affect the final risk score. This allows for a clearer interpretation of how the risk reduction measures are affecting the overall level of risk than can be made in the Shoreham Airshow Air Display Risk Assessment.

Table 3 Replication of Table 3 from the 2015 Shoreham Air Display Risk Assessment [2] showing the risk tolerability matrix

Probability / Outcome	Extremely Improbable	Improbable	Remote	Occasional	Frequent
Catastrophic	Review	Unacceptable	Unacceptable	Unacceptable	Unacceptable
Hazardous	Review	Review	Unacceptable	Unacceptable	Unacceptable
Major	Acceptable	Review	Review	Review	Unacceptable
Minor	Acceptable	Acceptable	Acceptable	Acceptable	Review
Negligible	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable

Table 4 in the risk assessment lists each of the 10 identified hazards and considers each in turn. It provides the hazard description, the severity and probability ratings and the risk level rating from the risk matrix. A list of mitigation measures, actions required, and who should perform the action is given. Each hazard is signed off by the FDD although, as has already been stated, the signature appears to be a digital one, the date is four months after the date of the draft risk assessment, and the date is the same as the preceding year's assessment with just the year changed. Table 4 replicates the Hazard 1 information in Table 4 in the Shoreham Air Display Risk Assessment.

Table 4 Replication of Table 4 from the 2015 Shoreham Air Display Risk Assessment [2] showing the Hazard identification and mitigation for Hazard 1

Hazard Number	Hazard Description	S	P	R	Mitigation	Actions Required	By Whom
1	Airside Unauthorised Access	M	I	R	Full crowd barriers in place.	All security staff to be briefed prior to the show.	RAFA
					There is only 1 access point to airside at the Airport terminal building. Access to airside is controlled by security staff and only duly authorised and identified personnel will be permitted to enter airside. Crowd barrier line is observed where possible by ATC and continually patrolled by Marshalls.	Security guards in place at all entry points to prevent unauthorised access.	RAFA
						Crowd barriers inspected daily for security during show.	RAFA
						FCC and ATC briefed to maintain a watch of the crowd line.	FDD, FCC & SATCO[1]
					Two-way radio contact with all aircraft on circuit. Pilots fully briefed on "stop action" instructions.	Procedures in place to be reviewed daily for currency and relevance.	Daily Show Debrief
Name	REDACTED Flying Display Director				Signature	Assessment Date 14 August 2015	

[1] SATCO = Senior Air Traffic Control Officer

2.2.7 The hazard assessments

Detailed comments on the individual hazards assessed are given in Section 2.3, but there are a number of comments that apply to all of the hazards. In particular:

- The hazard is not always clearly defined and described;
- Most of the mitigation measures and actions do not go beyond those given in the code of practice;
- There is no information linking the mitigation measures and/or actions required with a reduction in the level of risk;

- There is no assessment performed to determine whether the proposed mitigation measures and actions required are sufficient;
- There is no demonstration that the risks have been reduced ALARP;
- There are no measures listed which have been proposed and discounted, with reasons given as to why they have not been considered further. In a standard risk assessment, it would be expected that additional measures could be identified that may not be practicable, either in terms of implementation or cost. This process should be recorded.

There is insufficient evidence that the proposed mitigation measures reduce the risk ALARP, or that all practicable mitigation measures and controls have been considered, for all of the hazards identified and described in the Shoreham Air Display Risk Assessment.

2.2.8 Risk mitigation table

Table 5 in the Shoreham Airshow Air Display Risk Assessment lists each of the hazards, the original risk rating and the final risk rating, after the actions required identified in Table 4 of the risk assessment have been implemented. Table 5 in this document replicates the table given in the Air Display risk assessment.

Hazards 3 and 4 are erroneously listed as being "Review", which is an error that occurred in Table 4 of the risk assessment and will be discussed in more detail in Section 2.3. This is possibly also true of Hazard 7. In all cases, the statement is made that the required actions reduce the risk to "Acceptable". A summary is then made of the number of hazards that have been reduced from "Unacceptable" (at least 2 fewer than should be the case) or "Review" to "Acceptable" and how many remain in each category (i.e. all 10 are at level "Acceptable" after the actions required have been implemented).

There is no argument given as to why each of the hazards has been reduced to "Acceptable". In the guidance provided in CAP 403 [4], the tables assessing each hazard contain a column that allows it to be seen whether the likelihood or severity has been reduced by the mitigation measures (although no justification is given for the reduction). This is followed through so that the final risk rating is given, after the mitigation measures have been considered. In the Shoreham Airshow Air Display Risk Assessment, no link is made between the mitigation measures/actions required and the reduction in the severity or likelihood, and consequently the overall risk.

In the examples given in CAP 403, not all of the risks are reduced to the "Acceptable" region, as expected in standard risk assessment practice. It is unlikely that an event that has the potential to have catastrophic consequences will fall into the "Acceptable" region, unless the event itself (in this case, flying an aircraft) is prevented entirely. It is also not required that the risk is reduced this low, according to standard risk assessment guidance [6]. The requirement is to show that all practicable measures have been considered and implemented and that the risk is reduced ALARP (which would fall into the "Review" category in the matrix given in the Shoreham Airshow Air Display Risk Assessment).

Table 5 Replication of Table 5 from The 2015 Shoreham Air Display Risk Assessment [2] summarising the Hazards and risk mitigation

Hazard #	Description	Risk Mitigation
1	Air Unauthorised Access	Risk rated as "Review". Required actions reduce impact to "Acceptable".
2	Mid-air collision – Display and non-Display aircraft	Risk rated as "Unacceptable". Required actions mitigate risk to "Acceptable" provided all aspects of the actions are sustained particularly the emphasis on visual lookout by ATC and FCC.
3	Mid-air collision – Display Formation	Risk rated as "Review". Actions required and limitations on formation items displaying at Shoreham reduce this to "Acceptable".
4	Ejector seat impacts crowd	Risk assessed as "Review". Actions reduce the risk to "Acceptable".
5	Loss of control due to pilot disorientation	Risk rated as "Unacceptable". Required actions mitigate risk to "Acceptable". Poor weather / lack of horizon warnings included in Pilot's Brief.
6	Location Road and of local built up areas	Risk assessed as "Unacceptable". Action required reduce the risk to "Acceptable".
7	Public Assembly on A27 and local roads	Risk rated as "Review". Required actions as agreed with the Police reduce impact to "Acceptable".
8	Aircraft Crash Outside the Airfield Boundary	Risk assessed as "Unacceptable". Action required reduce the risk to "Acceptable". Real time monitoring of display items by the FCC ensure compliance with the relevant rules and regulations.
9	Fast jet aircraft collision into crowd area	Risk assessed as "Unacceptable". Action required reduce the risk to "Acceptable". Real time monitoring of display items by the FCC ensure compliance with the relevant rules and regulations.
10	Fatigue amongst key safety staff	Risk rated as "Review". Required actions reduce impact to "Acceptable"

The statements made in the Shoreham Airshow Air Display Risk Assessment indicate a lack of understanding of how to perform a risk assessment and its purpose. It provides no confidence that a comprehensive process has been undertaken or that serious consideration has been given to the risks.

2.3 COMMENTS ON THE HAZARD ASSESSMENTS

2.3.1 Hazard 1: Airside unauthorised access

The severity classification for this hazard is given as "M". Given that there are two severity classifications that begin with M, "Major" and "Minor", it should be made clearer which has been assigned. The combination of a likelihood of "Improbable" and a risk matrix category of "Review" implies that the severity is "Major", but this has to be inferred from other information and is not explicit.

- ***Mitigation***

The first two mitigation measures listed relate to the use of crowd barriers and preventing the public from entering prohibited areas, specifically the terminal building and airside. These measures can be considered to be standard practice as they are listed in paragraph 3.16 of CAP 403 [4].

There are two additional points in the second mitigation measure, however, concerning preventing the public entering airside at the airport. The first is that "there is only 1 access point to airside at the Airport terminal Building". It is not clear whether this is a general statement with regards to the layout of Shoreham Airport, or whether this is an additional measure that has been imposed for the duration of the airshow.

The second additional point for the mitigation is that the "Crowd barrier line is observed where possible by ATC [Air Traffic Control] and continually patrolled by Marshals". Paragraph 3.16 in CAP 403 explicitly states that marshals control the movements of spectators throughout the event. The use of ATC to monitor the crowd is not mentioned in CAP 403. As ATC are employed to monitor the airspace around the airfield and to instruct pilots on appropriate actions to take for the duration of their flights, it does not seem reasonable that they are also monitoring the crowd line. In addition, they may not have a clear line of sight to the crowd line.

It should be noted that it has been assumed that ATC refers to Air Traffic Control due to SATCO (Senior Air Traffic Control Officer) being responsible for ensuring that the required actions are carried out. This applies throughout this report. ATC can also refer to Air Training Corps, whose cadets are sometimes used in an official capacity at airshows. All acronyms should be expanded on first use to avoid the ambiguity seen here.

These two additional points made concerning the mitigation measures are either unclear or impractical.

The third mitigation measure concerns two-way radio contact with all aircraft in circuit and the pilots being fully briefed on "stop action" instructions (i.e. terminate the display). Paragraphs 3.47 and 3.48 in CAP 403 consider the use and allocation of radio frequencies. This states the requirement for some level of radio communication and, where possible, that a quiet frequency for use during the flying display should be allocated. If only one frequency is available, then the Flying Display Director (FDD) must make this clear in the written and verbal briefings. In other words, this is standard practice for running an airshow.

There is a section in CAP 403 on pilot briefings (paragraphs 3.50 to 3.54) with details of what is required to be covered in the briefings given in Appendix C of CAP 403. One of these requirements considers procedures for the cancellation or the variation of the programme. It is not explicitly stated that pilots should be fully briefed on "stop action" instructions, but it could be inferred from the list of areas to be covered in the briefings.

There are no practicable mitigation measures above and beyond the code of practice that are considered under this category.

- ***Actions Required***

The first action required states that all security staff should be briefed prior to the show. Whilst this requirement is not specifically stated in CAP 403, marshals are expected to control the movement of spectators (paragraph 3.16). It could be expected, therefore, that all marshals will have been briefed on their role prior to commencing work at the show.

The second action required states "Security Guards in place at all entry points to prevent unauthorised access". This is in relation to the mitigation measure of limiting access to the terminal building and to airside. As stated previously, CAP 403 states that marshals are expected to control the movement of spectators throughout the event.

The third action states "Crowd barriers inspected daily for security during show". Paragraph 3.16 of CAP 403 clearly states the need for effective barriers. It does not explicitly state that the barriers should be regularly inspected, but the phrase "effective barriers" used in the document implies the need to ensure that they are capable of restraining the crowd throughout the duration of the show.

The fourth action is not in CAP 403 and is "FCC [Flying Control Committee] and ATC [Air Traffic Control] briefed to maintain a watch of the crowd line". This appears to be an additional measure but, given the level of responsibility that the FCC and ATC have for ensuring that the flying display is proceeding as planned (e.g. the pilots are following instructions, minimum heights are observed etc.) then it is not clear how the FCC and the ATC can also be watching the crowd line.

This is an instance of where implementing a control measure may decrease the risk from one hazard but may increase the risk from another (e.g. in this case, potentially hazardous situations in the air may not be seen in time to prevent them occurring). The implications of this measure do not appear to have been assessed adequately.

The final action relates to the mitigation measure for two-way radio contact with all the aircraft in circuit and pilots being briefed on "stop action" instructions. It states "Procedures in place to be reviewed daily for currency and relevance". CAP 403 does not explicitly state that the items covered in the briefing should be reviewed daily. It does, however, state that briefings must be given on each day of the flying and it also provides a list of items that should be covered in the briefing. It could be inferred that any changes pertinent to the briefing would be covered in the daily briefing. It should be noted that the risk assessment does not state that any changes to the procedures should be recorded, which is an oversight.

- ***Summary***

The mitigation measures identified are from the code of practice and would be expected to be the basic activities required for running an airshow.

Only one of the actions required potentially appears to go beyond the code of practice but it is debatable as to whether this action is practicable.

No assessment seems to have been made as to whether any of the mitigation measures and actions required are suitable and sufficient.

No specific measures for the Shoreham Airshow have been included in the risk assessment. The lack of additional measures may be because there is nothing practicable that can be done. As no recorded process has been undertaken to determine what measures are possible, however, then it is not possible to state that all measures have been considered, or whether any additional ones have been considered but discarded for a legitimate reason.

2.3.2 Hazard 2: Mid-air collision – display and non-display aircraft

The first comment on this part of Table 4 is that there are a number of acronyms that have not been explained. Whilst the people looking at and creating the risk assessment are likely to be familiar with the terms, it should not be assumed that everyone who needs to see the document is familiar with these terms and either a glossary should be provided or the acronyms expanded on first use.

It is not clearly stated in the table whether the hazard is just to the pilots themselves or to the people on the ground as well. Intuitively it will be both but it should be clearly stated who can be adversely affected by the hazard.

- ***Mitigation***

The first item listed under the mitigation column refers to NOTAMs (Notice to Airmen) and a Temporary Restricted Airspace (RA(T)). A NOTAM is required to alert pilots of potential hazards along a flight route or at a specific location. It is therefore a requirement that NOTAMs are in place to notify pilots of additional hazards posed by the airshow. Similarly, RA(T)s would be expected to be in place for the duration of the display, to ensure that only display aircraft are in the airspace. Considering and making arrangements for airspace and air traffic management requirements forms part of the preliminary planning for airshows listed in paragraph 2.23 of CAP 403 [4]. This mitigation measure does not go beyond standard practice that would be expected for an airshow.

The second mitigation measure concerns closing the east side heliport for the Battle of Britain Memorial Flight (BBMF) and for other displays on request. An immediate question that arises, that is not explained, is why the heliport is only closed for this display? If the use of the heliport increases the risk of a mid-air collision, then the possibility of closing it for all displays should be considered and if there is a logical reason why this is not the case then this should be recorded.

If the risk of a mid-air collision with a helicopter from the heliport and a display aircraft is considered large enough to warrant closing the heliport, why is that decision left with the pilot and not the FDD who is in overall charge of safety at the event? If the heliport is not closed for all displays then, potentially, all pilots should be asked if they require the heliport to be closed and the FDD then makes the final decision, feeding back to the pilot. Refusing the request to close the heliport would require a valid reason that should be recorded.

The third mitigation measure refers to the ATC VCR (Air Traffic Control Visual Control Room) having full time visual surveillance. This would fall under the category of good practice, but may be limited by the design of the ATC VCR.

- ***Actions Required***

The first action pertains to briefing the pilots on stop actions. Although this is not explicitly covered in Appendix C of the CAP 403, which covers the written and verbal briefings to pilots, it could be considered part of the "Display procedures" in the verbal briefing or "Procedures for cancellation or variation of programme" in the written briefing.

The second action states that the display will only be carried out in weather conditions stipulated in CAP 403 or higher limits. In other words, this is an example of following the code of practice.

The third action relates to the mitigation measure of closing the heliport, if requested to do so by the pilots. It is stated that "Air Display profiles are flown within reserved airspace". It is presumed that this means that the displays are flown within the airspace that has been restricted using a RA(T) (Temporary Restricted Airspace) and that does not contain helicopters from the east side heliport, which has been closed. It would be expected that the display itself (excluding the approach to the airport if pilots are flying in from elsewhere) would be flown within the reserved airspace. Again, this is standard good practice that would be expected from an airshow.

The final action states that the Flying Display Director (FDD) must remind ATC (Air Traffic Control) and the Flying Control Committee (FCC) to "maintain visual lookout of display area and environs and intervene, if required, with the display aircraft by radio to prevent collision". ATC continually monitor what is occurring in the air as part of their job and CAP 403 [4] states in paragraph 2.14 that "The FCC should have the clear authority of the Event Organiser to curtail or stop, on the grounds of safety, any display item, or, in extreme cases, the whole flying display" i.e. this forms part of the role of the FCC. Although this measure may help to prevent some accidents, there is an issue as to how effective this action would be in practice for incidents where there could be short timescales from noticing an arising issue to flight crew being informed and responding. An assessment should be performed as to the effectiveness of this measure in mitigating the risk of a mid-air collision.

- ***Summary***

There appear to be no mitigation measures or actions required listed in the hazard identification that are over and above following the code of practice, with the exception of the potential closure of the heliport. Given that this hazard falls into the "Unacceptable" region of the risk matrix, it would be expected that additional measures and actions would have been considered, even if later found to be impractical.

2.3.3 Hazard 3: Mid-air collision – display formation

This concerns a mid-air collision involving members of a display team. The severity has been assessed as being catastrophic and the likelihood as improbable. On the risk matrix, this gives it a classification of "Unacceptable". In the table, however, it is recorded as "Review". This is an error and, checking against the 2014 and 2013 versions of the assessment, it is one that has been there in previous years and not corrected. This adds weight to the suggestion that that the risk assessments have been reused without proper and due consideration of the hazards and risks each year.

- ***Mitigation***

The first mitigation measure states that only recognised display teams with the appropriate authorisations will be allowed to display at Shoreham Airshow. This is a standard requirement, as detailed in Chapter 1 of CAP 403 [4].

The second mitigation measure states "Display airspace maintained to reduce/eliminate possibility of incursion by unknown traffic". There are two points to make here. Firstly, it is standard practice and a role of Air Traffic Control to ensure the airspace is clear, and that it is maintained as such. Secondly, the hazard under consideration is a mid-air collision between two display aircraft. This measure would appear to be more appropriate under Hazard 2.

- ***Actions Required***

In terms of the actions required, the first one, which requires confirmation of the Display Authorisations, is again standard practice and a requirement for holding Air Displays, as detailed in CAP 403. The second action is "ATC monitor airspace". This is part of the role of air traffic control.

The third requirement relates to the participants being familiar with stop instructions, which is to be covered during the mandatory briefings. This has been discussed previously in Section 2.2.7 and can essentially be considered to be following the code of practice.

The final action relates to the weather conditions, which are stipulated within CAP 403. It is stated that the higher of the team requirements or CAP 403 should be used.

The risk is incorrectly classified and there are no mitigation measures or actions required that are above and beyond the code of practice for an airshow. There is no assessment made as to whether these measures are suitable and sufficient. No additional measures appear to have been considered that might be specifically relevant for the Shoreham Air Display. Given that the risk level should be correctly identified as “Unacceptable”, it would be expected that additional measures would have been identified and considered, even if later dismissed. This does not appear to be the case.

2.3.4 Hazard 4: Ejector seat impacts crowd

For this hazard, the severity has been assessed as catastrophic, the probability has been assessed as improbable but the risk ranking has been given as “Review” even though, according to the risk matrix, it should be “Unacceptable”. This is an error that can also be seen in the 2013 and 2014 assessments.

- ***Mitigation***

There is one mitigation measure listed, which has tracked changes applied to it but is essentially the same as previous versions of the risk assessment. The measure essentially states that aircraft manoeuvres must be commenced before the 230 m display line (i.e. 230 m from the crowd line), or, for military aircraft in excess of 300 knots, at 450 m from the crowd line. The 450 m requirement is greater than that specified in CAP 403 [4] but is only applied to military aircraft. It is not made clear why any civilian aircraft that satisfy these criteria are not included in this mitigation measure. The distinction should be made on the capabilities of the aircraft, rather than on whether it is military or civilian.

- ***Actions Required***

Under the “actions required” section, there is a generic statement made about monitoring other events and meeting any changes to the rules stated in CAP 403. These actions would be expected from following the code of practice for risk assessments but, as has been detailed in Section 2.2.5, there is no recorded evidence that this process has been followed.

The remaining action is to review wind effects daily to “ensure that any on crowd wind is not so strong as to increase likelihood of ejector seat entering crowd area in the aftermath of ejection”. There is no indication given as to what these wind limits are likely to be. Also, there are different types of ejector seats available, which will behave in different ways on release. This does not appear to have been considered.

- ***Summary***

The risk for this hazard is assessed as lower than it should be, the mitigation measure appears insufficient when all aircraft are considered and the actions required are too vague. There is no evidence that all mitigation measures have been identified and assessed, or that those considered are suitable and sufficient.

It should be noted that only the risk from an ejector seat falling into the crowd has been assessed. Other objects falling or crashing into the crowd, such as the aircraft itself, have not been assessed.

2.3.5 Hazard 5: Loss of control due to pilot disorientation

This hazard is listed as being "Unacceptable".

- ***Mitigation***

The first mitigation measure for this hazard requires pilots to have the required display currency "at least as required by CAP 403". This forms part of the standard guidance as detailed in Chapter 1 of CAP 403.

The second mitigation measure states that pilots must operate to the more stringent of the weather limits given in CAP 403, and their personal clearance. The recommended weather minima are given in paragraphs 3.43 to 3.46 in CAP 403. Paragraph 3.46 also states that "It should be borne in mind that participants may be further restricted by their licence or rating privileges". This mitigation measure is therefore following the code of practice.

The third mitigation measure concerns limiting radio transmissions during the display. The use of radio frequencies is covered in paragraphs 3.47 and 3.48 of CAP 403. It is stated in CAP 403 that, ideally, a quiet frequency should be allocated for use during the flying display, with another allocated to administration tasks. If only one frequency is available, then "the FDD must emphasise, in the written brief and at the verbal briefing, the need for good Radio Telephony (RT) discipline and for the minimum use of RT". This measure is another example of following the code of practice.

The fourth measure states "Each display pilot has the option to have the east side Heliport closed during his/her display". It is unclear what effect this has on pilot disorientation. If it is perceived as a potential risk that could distract pilots, then the option of closing the heliport for all of the displays should be assessed as a separate specific hazard in the risk assessment.

The final mitigation measure concerns marking the display line with Day-Glo markers to aid orientation. Paragraph 3.20 of CAP 403 states "Where the display line is not clearly delineated by a paved runway or other obvious line feature it should be marked with Day-Glo pyramids or panels, whitewashed lines or by some other suitable method". This mitigation measure is another example of following the code of practice.

- ***Actions Required***

The five actions required relate directly to the five mitigation measures. The first one is actioned for the FDD and is to ensure that all the CAP 403 and Display Regulations requirements are followed. This forms part of the role of the FDD as detailed in Chapters 1 and 2 of CAP 403. It is not clearly stated in CAP 403 that the FDD will ensure that the display pilots have the required authorities (which the pilot obtains from the CAA for civilian aircraft and the Ministry Of Defence (MOD) for military aircraft) but it is made clear that the FDD is responsible for the organising of the flying display and that the pilots must have the relevant display authorisation. It therefore appears reasonable that the FDD would be expected to review display pilot authorisations as part of the standard practice for airshows.

The second action is on the FDD and Chair of the FCC to monitor weather conditions before and during the display. CAP 403 defines the type of events that may occur at specified minimum weather conditions, but it is not clearly stated how the weather is monitored or by whom. In order to observe these conditions, however, people must be in place who are monitoring the weather conditions. This would therefore fall under the category of following the code of practice.

The third action is to ensure that ATC (Air Traffic Control) are briefed to minimise the number of radio transmissions during the display. This action should be on all people with radio control (the FDD and the FCC, as well as ATC). It also forms part of the guidance given in paragraph 3.48 of CAP 403.

The fourth action is to "confirm heliport suppression requirements during the display briefing". This is an action that is specific to Shoreham Airshow. It would appear to be essential, if the option of closing the heliport is to be given to the pilots.

The final action states "Mandatory daily briefing to all display pilots to emphasise the need for caution in reduced visibility or lack of horizon". A daily briefing forms part of the guidance given in paragraphs 3.50 to 3.54 of CAP 403. Pilots are given details of current and forecast weather conditions, along with any local conditions or effects as part of the verbal briefing detailed in Appendix C of CAP 403. The note in bold in paragraph 3.43 of CAP 403 states "Pilots and FDD's should give greater consideration to visual reference when there is little or no defined horizon." This action is another example of following the code of practice that would normally be expected at an airshow.

No assessment appears to have been made to determine if the measures and actions are sufficient for controlling the risks. The only measure above and beyond the code of practice relates to the closing of the heliport. It is not obvious why this measure is deemed relevant to the hazard under consideration.

- ***Summary***

There are no mitigation measures or actions required that are above and beyond the guidance, with the exception of the closure of the heliport. No assessment has been made as to whether these measures are sufficient.

If the heliport is considered a credible risk, then the option of closing it for all displays should be assessed as a separate specific hazard in the risk assessment.

There is no indication as to whether any method has been used to identify and discount alternative measures. Given that the risk level was identified as "Unacceptable" for this hazard then it would be expected that alternative measures would have been identified and considered.

2.3.6 Hazard 6: Location of local built up areas

This hazard has been assessed as having a risk level of "Unacceptable". It has been subject to some changes to the text when compared to earlier versions of the risk assessment, but this has left the hazard description as "Location of local built up areas including". Either the word "including" should no longer be there, or whatever should have been included is missing. It should be noted that the modifications from the previous version are marked up as "tracked changes", confirming the draft nature of the document.

It should be noted that built up areas are not a hazard. The hazard relates to aircraft flying over them and crashing, either above the area or into a building within the area. Alternatively, the hazard may be to the aircraft, perhaps through particularly tall buildings, an element of distraction etc. In either case, the hazard should be more clearly described.

- ***Mitigation***

The first mitigation listed is “The major built up areas lie close to the south-west of the display area”. This is not a mitigation measure but a description of the location of the population. Similarly, the second mitigation is “A small built-up area lies south of the display area along the coastal strip”. This is again a description and does not correspond to a mitigation measure. If the inclusion of these locations is to define no fly areas or areas where there are restrictions on minimum heights, etc, then this should be explicitly stated to make this clear.

The third mitigation states that overflight of Lancing College is prohibited. The final mitigation is a modification from the previous version of the risk assessment and states that revised restrictions with respect to over flying congested areas have been agreed with the CAA. This includes the new football ground in the area.

The first mitigation measure does not relate to the main built up areas around the airfield, where it might be considered that the consequences of the hazard are greater (whatever actual definition of the hazard is used in this instance). It is not stated in the assessment documents what the revised restrictions over the congested areas requires pilots to do in their display to minimise the risk.

- ***Actions Required***

In terms of the actions required, the first relates to the restrictions being covered in the mandatory display briefing. This is covered in Appendix C of CAP 403 and can therefore be considered to be following the code of practice.

The second action relates to the minimum height that is mandated over the built up areas to the south west. The tracked changes indicate that this has reduced from 1500 feet above ground level (agl) in 2014 to 1000 feet in 2015. No justification is given for this, even though this action would intuitively lead to an increase in the risk of an aircraft crashing in a built up area (e.g. if the pilot loses control they have less space and time to implement corrective measures).

It is stated in the assessment that “Aircraft to be visually monitored to ensure compliance with this requirement”. This statement also applies to the next action, which gives the minimum height above the built up areas to the south west of the airfield as 500 feet agl, and forms the entirety of the fourth action which relates to the no flying zone over Lancing College.

In all cases, a person on the ground needs to be able to accurately assess the height of an aircraft that also may be some distance away horizontally. This mitigation measure does not consider the possibility that these personnel may be distracted by events occurring on the ground or in other parts of the airshow.

Alternative methods to assess the height, such as radar, are not mentioned and so it must be assumed that they have not been considered. It could be that an assessment would reach the conclusion that the implementation of radar would be too costly when compared to the decrease in the risk but the reasoning for this should be recorded. This is particularly true for this hazard, which has been identified as falling into the “Unacceptable” region of the matrix due to the potential for many people to be killed should an accident occur. The more serious the risk, the more has to be done to control the risk to a tolerable level.

The final action states that the revised restrictions are to be briefed to the display pilots, both in the written and verbal briefs. This forms part of Appendix C in CAP 403 and is another example of recommended guidance and hence following the code of practice.

- ***Summary***

It is not entirely clear what the scenario under consideration is for this hazard.

Two of the mitigation measures are descriptions of areas, and are not mitigation measures to control the hazard or risk. One of the mitigation measures identified relates to a specific area and another measure does not detail what revised restrictions are in place.

The actions given are either within the CAP 403 guidance or have serious limitations.

No assessment has been made as to whether the identified measures and actions are sufficient, and no additional measures appear to have been assessed.

2.3.7 Hazard 7: Public assembly on A27 and local roads

The first issue with this hazard is that public assembly on the roads is not a hazard in itself, unless it impacts on the flying displays. The hazard is that an aircraft could crash on this area, where a large number of people may be congregated. If this is the case, then the consequences are likely to be catastrophic with the potential for multiple fatalities. In the risk assessment, however, it has been categorised as being "Hazardous" and the overall risk rating has been given as "Review". If the more accurate category of "Catastrophic" is used, the risk rating would be "Unacceptable".

The probability rating for this hazard is given as "Improbable". This is where it becomes important that the hazard is clearly defined. If the hazard is an aircraft crashing on this population area, then the probability rating is accurate. If, as appears to be the case in the risk assessment, the hazard is the likelihood that people stop on the local roads to watch parts of the airshow, then the likelihood rating must be "Frequent". Regardless of whether the consequence rating is given as "Hazardous" or "Catastrophic", a likelihood rating of "Frequent" leads to an overall risk rating of "Unacceptable".

- ***Mitigation***

In terms of mitigation, the risk assessment states that police take action to restrict parking on the A27 and other areas are monitored where possible.

- ***Actions Required***

The actions are given as "Arrange for A27 and attractively placed parking areas to be cordoned off". Neither of these seems sufficient to lower the likelihood that people will congregate around the airfield. An obvious additional measure that is not mentioned at all is the possibility of closing the A27 and/or any surrounding roads. This may not be possible but should be considered. It may not also prevent people from walking along the side of the road, but does make some attempt to stop people standing at the edge of the airfield.

Another measure that has not been considered is the possibility of preventing aircraft flying over this area. This would significantly decrease the likelihood of an aircraft crashing onto the crowd.

The risk assessment should recognise that people are likely to congregate outside the airfield boundary and that they need protecting from the consequences of any incident that occurs during the airshow. It is not sufficient to say that attempts will be made to prevent them stopping in the first place, unless it can be shown that they are completely prevented from congregating.

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There are also other issues concerning the congregation of people, such as people trying to gain access to the airfield from the perimeter. Given the broadness of the title of the hazard, it would be expected that a number of additional issues would need to be addressed. This has not occurred.

- ***Summary***

The hazard is not clearly defined and the severity and risk ratings are too low.

The mitigation measures and actions appear insufficient and there is no evidence that any alternative measures have been considered.

2.3.8 Hazard 8: Aircraft crash outside the airfield boundary

One immediate point to note with this hazard is that it is not specified whether the mitigation and actions required apply equally to all aircraft or only to certain categories. For example, do all aircraft have to observe the same minimum height restrictions? Are some aircraft prohibited from overflying particular areas? More clarity is required.

- ***Mitigation***

The first mitigation measure states that pilots must observe the normal "Rules of the Air" when outside the display area. This is standard practice outside any area that has non-standard regulations applied to it.

There is a caveat in the "Rules of the Air" that exempts pilots from following these rules outside the display area if they are within 1 km of people congregated for the air display and with agreement from the competent authority, provided there is a suitable risk assessment. The normal "Rules of the Air" impose height restrictions and areas of no overflying. This has particular relevance for any people congregated outside the airfield boundary (as in the case of Hazard 7). If this exemption has been granted for Shoreham Airshow, then the first mitigation measure listed (normal "Rules of the Air" apply outside the display area) is not correct.

The second mitigation measure states that there are major restrictions on the display aircraft that require specific minimum flight heights over specific locations around the display site. The third states that the pilots will be briefed on the restrictions. Paragraph 3.3 of CAP 403 states "FDDs should consider imposing minimum height restrictions over local sensitive and congested areas". It is stated that the restrictions should be clearly declared in the flying display instructions. These two measures are therefore following the code of practice.

- ***Actions Required***

The first and third actions, relating to briefing of crews on safety requirements and mandatory operating regulations, and direct radio contact between the pilots and the FDD or CFCC are both following the guidance given in CAP 403 (Appendix C for the details of the briefing and paragraphs 3.47 and 3.48 for the use of radio).

The second action relies on the FDD and FCC being able to correctly ascertain whether the regulations regarding minimum heights and the display programme are being observed, and to have the ability to stop the display at any time. It could be argued that it would be difficult for anyone on the ground, regardless of their own flying experience, to be able to always correctly determine whether the regulations are being complied with. In addition, does the "agreed display programme" include the manoeuvres that will be performed in that part of the display, or just the order of the displays on that day? If it is the former, then it will be difficult for a person on the ground to judge whether or not all aspects of the display have been followed. If it is the latter, then it has little relevance to the hazard under consideration.

The ability to issue a stop command is given as part of the third action. This forms part of the guidance in CAP 403 (e.g. paragraph 2.14). In the event of an emergency, by the time the person on the ground has realised that there is an issue, it may be too late to issue a stop command. Whilst the ability to do so is essential, it should be recognised that it may have limited effectiveness.

No alternative mitigation measures or actions appear to have been considered. In particular, the possibility of using radar to monitor the flights has not been discussed. The option may not be feasible for a number of reasons but it should have been considered and reasons given as to why it is not suitable. The lack of consideration of such a measure leads to uncertainty as to whether or not all possible measures have been considered.

- ***Summary***

It has not been clearly stated in the assessment whether all aircraft are subject to the same measures or whether these apply to just some of the aircraft.

The mitigation measures and actions required are following the code of practice, but no assessment has been made as to whether or not these measures are sufficient to control and reduce the risk. One of the identified mitigation measures outlined may not apply to all areas outside of the airfield boundary, and some of the actions required rely on a degree of visual accuracy on behalf of the FDD and FCC.

2.3.9 Hazard 9: Fast jet aircraft collision into crowd area

This hazard has been assessed as having a risk level of “Unacceptable”.

- ***Mitigation***

It appears to only consider military aircraft and the only mitigation relates to the display line for aircraft that can reach speeds in excess of 300 knots. In this instance, the display line is moved to 450 m from the crowd line. This is greater than the minimum required in paragraph 3.25 of CAP 403 [4] but there is nothing to indicate why it only applies to military aircraft and not all aircraft that are capable of speeds of 300 knots.

- ***Actions Required***

The actions required are very similar to those listed for Hazard 8 and represent following the code of practice (e.g. briefing crew on safety requirements and having radio contact with the display pilot). As in the case of Hazard 8, there appears to be a large reliance on the FDD and FCC being able to monitor the flights on the ground and notice if the aircraft is outside of the specified limits (either vertically or horizontally if the “display programme” is taken to mean the details of the specific display).

The ability of the FCC to issue a stop command is listed as an action to reduce the risk. Whilst this is obviously essential, in an emergency there may not be time to issue such a command and for the pilot to have sufficient scope to act upon the stop command.

There are no other mitigation measures or actions considered. Alternatives are not discussed or mentioned.

- ***Summary***

This hazard has been identified as applicable to military aircraft only. Civilian aircraft have not been considered, although some are capable of reaching speeds of 300 knots.

There is only one mitigation measure listed and whilst some of the actions represent following the code of practice there is nothing to indicate that the measures and actions listed are sufficient. Other actions identified are potentially impractical.

2.3.10 Hazard 10: Fatigue of essential safety staff

This hazard relates to the FDD, CFCC, FCC or ATC becoming fatigued, leading to impairment of their judgement so that safety is compromised. It must be inferred that fatigue could lead to these key personnel issuing an erroneous command which leads to aircraft collision, a crash etc. or that they miss an issue relating to the safety of the airshow.

The severity rating is given as “Hazardous” leading to a risk level of “Review”. It could be argued that, if fatigue of staff leads to safety being compromised, the consequences could be catastrophic (e.g. an aircraft crash). In this case, the risk level would be “Unacceptable”. It is important that the hazard is clearly defined in order that it can be ranked accurately in the risk matrix.

- ***Mitigation***

The only mitigation measures listed are that the ATC staff work to legal working requirements i.e. they follow the law, and that the FDD and FCC members are “familiar with the threat posed by personal fatigue and are used to monitoring for it in themselves and others”. This is a vague control that does not obviously reduce the likelihood or severity of the hazard.

A more effective specific measure would be to ensure mandatory regular breaks and a timetable that ensures no one is on duty for longer than a specified time. It should also be ensured that there are sufficient members of the FCC (and a deputy FDD) such that, should a member be taken ill for any reason, there are enough other members to cover the safety of the airshow. These controls may be in place during the show, but they are not mentioned in the risk assessment.

- ***Actions Required***

Two required actions are listed. The first relates to ensuring that the ATC staff follow the legal requirements. The second is on the FDD, CFCC and FCC to monitor their own and others’ work patterns and to rest individuals where fatigue is expected. All are to be reminded that they are required to make critical judgements throughout their duty periods and that they need “to self- and cross-monitor for individual fatigue and to report any concerns to (the CFCC)”.

This action places a large reliance on people noticing their own and others’ fatigue levels. At a busy airshow it may be difficult to notice how others are behaving, or if they are showing any signs of fatigue. Also, although work patterns are mentioned, it is not made clear as to how long people are expected to be on duty for, how long breaks are, and if there are sufficient staff to cover in the event of illness or fatigue. These controls should be explicitly defined as part of the risk assessment to make the mitigation and consequent reduction in risk levels clear in the assessment.

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- ***Summary***

The hazard is not clearly defined and the risk level may be too low.

The mitigation measures are either legal requirements or are too vague to control or reduce the risk levels.

The actions either ensure legal compliance or are potentially impracticable.

There is no evidence that an assessment was performed to determine if the actions and measures are sufficient. There is no record of any additional measures being considered.

2.4 HEALTH AND SAFETY EXECUTIVE (HSE) GUIDANCE

The HSE guidance, "Reducing Risks, Protecting People" (R2P2) [6] has been considered in relation to the Shoreham Airshow Air Display Risk Assessment, together with other published guidance [7, 8] and health and safety legislation [9]. One of the aims of R2P2 is to set out a framework for "decision taking by HSE which would ensure consistency and coherence across the full range of risks falling within the scope of the Health and Safety at Work Act". The document outlines the principles that HSE uses to assess and control risks and may be regarded as guidance on how HSE would expect others to consider control of health and safety risks.

The main point from the "Management of health and safety at work regulations 1999" [9] is the need for employers to have a risk assessment that is a "suitable and sufficient assessment" of the risks to the health and safety of employees and to the health and safety of persons not in their employ but who are exposed to risk through the employer's undertakings. In the case of the Shoreham Airshow, this means that the health and safety of the public watching the show, or in areas that could be affected by the show, needs to be considered, along with the health and safety of the people working at the airshow.

Gadd *et al* [7] builds on the work of R2P2 and highlights some of the common failings seen with risk assessments, i.e. the 'pitfalls' of risk assessment. The HSE guidance, "Managing for health and safety" [8] is primarily aimed at commercial businesses, but the concepts used are generally applicable and some of the practices can be applied to events such as airshows. The legislation [9] sets out the legal requirements with regard to managing health and safety in the workplace.

2.4.1 Hazard identification

Paragraph 87 of R2P2 discusses the issue of ignorance in relation to the identification of hazards. In order to counteract this, a "wide engagement of different disciplines and communities of interest in the characterisation of the issue" should be undertaken. It also states that a further measure is to be as open as possible to enable alternative views to be considered at an early stage.

Gadd *et al* discusses failure to identify all hazards as one of the common mistakes made in risk assessments. The "Managing for health and safety" guidance [8] discusses the reasons for doing what it calls "risk profiling", which is equivalent to a risk assessment. In particular it states that the outcome of the risk profiling will be that the right risks have been identified and that it will inform decisions about what control measures are needed.

All of the guidance states that a lack of awareness of the key hazards or risks is an indication of a lack of competence in the management of health and safety.

In relation to the Shoreham Airshow Air Display Risk Assessment, no detail is given as to how the hazards were identified. No list is given of the people involved in the process, or of any additional hazards that may have been identified but subsequently dismissed. HSL has been able to quickly identify additional hazards that appear to have not been considered, even without undertaking a full hazard identification process. This suggests that a thorough process was not performed for the Shoreham risk assessment.

Paragraph 93 of R2P2 considers hazards where there is a large degree of uncertainty involved and conventional techniques may not be applied to assess the risks. It is stated that the uncertainty may be overcome by "constructing credible scenarios on how the hazards could be realised and thereby making assumptions about consequences and likelihoods. The credible scenarios can range from a 'most likely' worst case to a 'worst case possible' depending on the degree of uncertainty". It further states that, although "risk assessments based on scenarios are inevitably narrower in scope than a full blown risk assessment, this may not be a serious limitation if the scenarios are carefully chosen to reflect what could happen in reality".

In the Shoreham Airshow Air Display Risk Assessment, some scenarios have been considered and an attempt made to determine how likely these scenarios are to occur. The general approach used is not unreasonable i.e. constructing a list of possible scenarios. However, it does not appear that all credible scenarios have been considered; there are insufficient scenarios to reflect what could happen in reality. There is a requirement to assess all "reasonably foreseeable" hazards (paragraph 6 in R2P2).

2.4.2 Risk mitigation

Paragraphs 99 and 100 in R2P2 are concerned with identifying options to consider how to manage the risks. In particular, the use of experience is given as one way of identifying options. It also states that possible good practice should be examined as a way of addressing the hazards identified. Good practice needs to be evaluated as to whether it is relevant and sufficient for the hazards posed.

If specific good practice is not available then good practice that applies in comparable circumstances should be considered, if it is directly transferable to the hazard in question or can be suitably modified.

Section 4.15 of Gadd *et al* lists a lack of consideration of further measures that could be taken as one of the errors often made in risk assessments. It states that it is necessary to explicitly identify possible risk reduction options and assess whether they are reasonably practicable. In addition, "all options, or combination of options that are reasonably practicable must be implemented". It goes on to say that each option should be measured against the present situation.

Most of the mitigation measures and actions required given in the Shoreham Airshow Air Display Risk Assessment are taken from the code of practice as laid down in the CAP 403 guidance [4]. No assessment appears to have been performed as to whether these are suitable and sufficient for each of the hazards considered, however.

R2P2 states that it needs to be determined if there are any constraints attached to using a particular option e.g. is it technically feasible, are there any legal constraints etc. Also, any adverse consequences for using a particular option need to be considered e.g. a measure may reduce the risk from one hazard, but increase it from another.

Section 4.18 of Gadd *et al* also states that it is necessary to examine the effectiveness of the risk control measure, and to consider whether any unexpected risks have been inadvertently created.

The "Managing for health and safety" guidance [8] states that health and safety controls that do not seem practical are an example of poor worker consultation.

These issues do not appear to have been considered in the Shoreham Airshow Air Display Risk Assessment. In many cases it is stated that the FDD and FCC will monitor the display from the ground and ensure that the minimum heights and the display plan are being observed. There appears to be no recognition of how difficult it might be to perform this role in practice, regardless of the experience of the FDD and FCC. There is a possibility that other issues regarding the airshow could distract these key personnel from this important activity. This suggests that the people involved in this action have not been properly consulted on the identified mitigation measure's practicality and effectiveness.

Paragraph 100 in R2P2 continues by stating that the "precautionary approach" should be used. In particular, as the degree of uncertainty increases, there is an increasing requirement for more stringent measures to mitigate the risks. This could be applied to all hazards where the consequences are "Catastrophic", as defined in the Shoreham Airshow Air Display Risk Assessment. In practice, this does not appear to have happened. The only measures listed for many of the "Unacceptable" risks are based on the code of practice and additional measures do not appear to have been considered.

R2P2 also refers to the relative costs and benefits of introducing a risk reduction measure. This can be used to determine whether or not a measure is proportionate to the level of risk involved. There is no evidence that this has formed part of the Shoreham Airshow Air Display Risk Assessment in either a quantitative or qualitative form.

R2P2 has a section on evaluating the effectiveness of any action taken (paragraphs 115 to 117), and this is also covered in Section 4.18 of Gadd *et al*. In particular, R2P2 states that procedures should be in place to review the decisions made after a suitable interval. These should establish whether the actions taken were effective in controlling the risk, and whether any decisions needed to be modified as a result of new knowledge. An assessment should be made as to whether the information gathered to identify the hazards and mitigate the risks was appropriate, and whether improved knowledge and data can help make better decisions. An assessment should be made as to what lessons could be learned from the process.

It is further stated that having a system for monitoring and evaluating progress provides a "good opportunity to assess whether such 'established standards of good practice' are out of date. New developments such as better knowledge of the risk involved and advances in technology may indicate that a higher standard would be more appropriate to control he risk". The "Managing for health and safety" guidance [8] further asks the question of whether lessons have been learned from occasions where things went wrong and how the health and safety performance is reviewed. There is a whole section concerning the investigation of accidents and incidents, another on reviewing performance and a further one on learning lessons.

In the Shoreham Airshow Air Display Risk Assessment, no mention is made of recording the effects of the risk reduction measures and actions, or any infringements of the regulations and measures. There appears to be no process for evaluating the measures in place and adjusting the risk assessment accordingly. There is no recorded process for learning lessons from previous incidents [10, 11, 12], and no reference to any incidents are made in the risk assessment. Although there is a statement made about routine reviews, there is no record of the reviews occurring. Additional information obtained by the AAIB indicates that the FDD requested comments from other people on the risk assessment prior to the 2015 airshow, but there is no record within the risk assessment of this. Not all of the comments from the reviewers have been fully incorporated, although legitimate issues were raised. There is no indication that lessons learnt from previous airshows or incidents formed part of the review. According to the "Managing for health and safety" guidance [8], having a poor incident history is an example of poor health and safety management.

2.4.3 Tolerability of Risk

R2P2 introduces the "TOR framework" in paragraph 122. TOR refers to the Tolerability of Risk and aids in the categorisation of a particular risk. HSE represents this concept by an inverted triangle with the risk increasing as you move up the triangle (see Figure 1). If the risk is low, then it will fall into the "Broadly acceptable" region. As the risk increases, it moves into the "Tolerable" region and high risks may end up in the "Unacceptable" region.

Risks in the "Tolerable" region are described in Gadd *et al* [7] as "typical of those that people are prepared to tolerate in order to secure certain benefits".

In terms of the Shoreham Airshow Air Display Risk Assessment, the comparable categories used in the risk matrix are "Acceptable" for the HSE "Broadly acceptable" category, "Review" for the HSE "Tolerable" category and "Unacceptable" for the HSE "Unacceptable" category. Risks in the HSE "Tolerable" and "Broadly acceptable" categories must still be controlled or reduced As Low As Reasonably Practicable (ALARP).

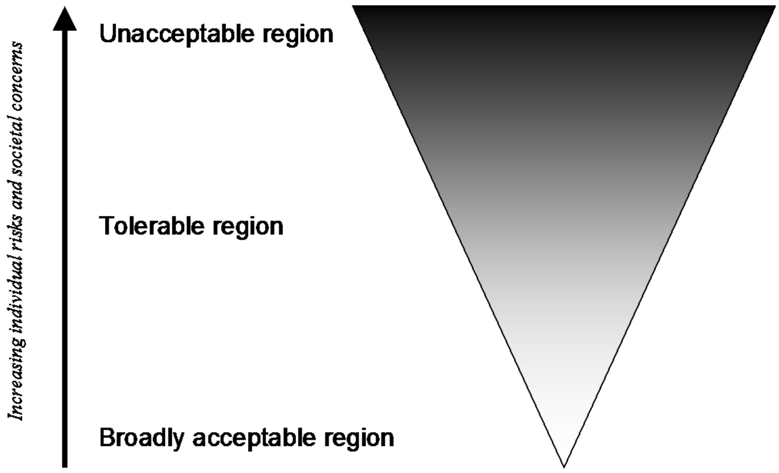

Figure 1 HSE Framework for the tolerability of risk [6]

In the description of the TOR framework, it is stated that any activity or practice that leads to a risk that falls into the "Unacceptable" region "would, as a matter of principle, be ruled out unless the activity or practice can be modified to reduce the degree of risk so that it falls in one of the regions below, or there are exceptional reasons for the activity or practice to be retained". In the Shoreham Airshow Air Display Risk Assessment, the authors have claimed that all risks have been reduced to the "Acceptable" level, including those that fell into the "Unacceptable" category initially. It appears possible that there has been a misunderstanding around what the various categories mean in practice and it has been assumed that an activity cannot take place if it falls into any region other than the "Acceptable" category of risk.

R2P2 makes it clear that, even if a risk falls into the "Broadly acceptable" region, reasonably practicable measures to reduce the risks should be considered. In the Shoreham Airshow Air

Display Risk Assessment, it is stated that no further consideration of the risk is required if it falls into the "Acceptable" region on their matrix. This contradicts the guidance in R2P2.

Within the "Tolerable" region in the TOR framework, it is expected that residual risks "are not unduly high and kept as low as reasonably practicable (the ALARP principle)". It is also expected that the risks are reviewed periodically to ensure that they still meet the ALARP criteria e.g. by considering any new techniques or information that have become available. An assessment is needed to determine whether the risks have been reduced ALARP. The starting point of such an assessment should be the present situation in the duty holder's undertaking or, if this is not possible, an option which is known to be reasonably practicable (e.g. one which represents existing good practice). Any additional measures are considered against this starting point, to determine whether or not they are reasonably practicable (paragraph 5 in Appendix C of R2P2).

Gadd *et al* [7] is more succinct and states that "Reducing risks ALARP means that if it is reasonably practicable to implement a risk reduction measure, it must be implemented." In addition, it states that "Duty holders should consider what more could be done to reduce a risk and why it is not being done i.e. whether or not it is reasonably practicable to implement any possible additional measures that are identified". A lack of consideration of ALARP or further measures that could be taken is recognised a common mistake made in risk assessments and is discussed in Section 4.15 of Gadd *et al*.

The Shoreham Airshow Air Display Risk Assessment does not appear to have regularly reviewed the risks as indicated by the very few changes that have been made over the years and the lack of a procedure for updating the assessment. Additional information obtained by the AAIB indicates that the risk assessment was sent to others for comment, but there is no record of this process and not all of the comments have been fully incorporated, although they raised legitimate concerns. No ALARP assessment appears to have been performed for any of the identified hazards. Instead, broad statements are made that all the risks have been reduced to "Acceptable". Additional mitigation measures have not been considered and assessed to see whether they should be implemented, under the ALARP principle.

2.4.4 Risk management

In R2P2, paragraph 141, it is stated that HSE start with the expectation that the controls in place "should, as a minimum, implement authoritative good practice precautions (or achieve similar standards of prevention/protection), irrespective of specific risk estimates". Paragraph 142 goes on to state that authoritative sources of relevant good practice include "guidance agreed by a body representing an industrial or occupational sector". In this instance, the guidance provided by the Civil Aviation Authority (CAA) should be implemented as a minimum.

R2P2 continues by stating that an assessment should be made as to whether adoption of the good practice is an adequate response to the hazards. In the Shoreham Airshow Air Display Risk Assessment, the guidance given by the CAA has generally been followed, although there are notable exceptions (e.g. not considering risk reduction measures for risks assessed as "Acceptable", using a risk matrix that does not explicitly consider the risks to people etc.). For all the identified hazards, however, mitigation measures are given but no link is made with a subsequent reduction in risk, or whether the reduction is sufficient.

In paragraphs 145 and 146 of R2P2, it is stated that there will be examples where existing good practice is insufficient to control the risks. In this instance, additional measures identified previously should be examined to determine if they lower the risks to an acceptable level.

Appendix J (Cont)

The Shoreham Airshow Air Display Risk Assessment makes no direct link between the mitigation measures and the risks, which is a common problem recognised in Section 4.18 of Gadd *et al*. In the majority of cases, no additional measures have been considered. Given that no process has been recorded for identifying both the hazards and mitigation measures, it is not clear whether any additional measures were considered and disregarded. If this was the case, the process was not recorded and the reasons for discarding additional measures have not been given.

In Section 4.19 of Gadd *et al* [7] the issue of not doing anything with the results of the risk assessment is discussed. It states that it is "essential that action is taken as a result of the findings of the risk assessment" and that it should not be considered a "paper exercise". At the end of the section it says "The assessment will almost inevitably result in recommendations for improvements and further actions to control and reduce risk …".

In the Shoreham Airshow Air Display Risk Assessment, no recommendations are made and the majority of the mitigation measures and actions do not go beyond the code of practice given in CAP 403 [4]. Additional mitigation measures do not appear to have been considered and assessed.

The second paragraph of Section 2 in the "pitfalls" paper [7] states "The findings from a risk assessment can be used to inform decisions as to whether any existing precautions or control measures are adequate, or whether additional prevention or control measures are needed. Risk assessment can also be used to perform a systematic comparison of different risk control/reduction options so that the optimal decision can be made".

In the Shoreham Airshow Air Display Risk Assessment, no assessment is made as to whether the proposed measures control the risk or whether additional measures are required.

An overview of the law on health and safety is given in the "Managing for health and safety" guidance [8]. It states that risk assessment must be "suitable and sufficient" which is interpreted as showing, amongst other areas, that the precautions are reasonable and the remaining risk is low, and the workers were involved or represented in the process.

In the Shoreham Airshow Air Display Risk Assessment, it is not recorded who was involved in the risk assessment process and no assessment has been given for the effects of identified mitigation measures and actions. No link is made between these measures and the final tables in the risk assessment stating that the risks are all "Acceptable" prior to the show.

In summary, the guidance given by HSE has not been followed and there appears to be a general lack of understanding of the risk assessment process and what is required.

3 CONCLUSIONS

A review of the 2015 Shoreham Airshow Air Display Risk Assessment [1] has been conducted. This has included a comparison with the corresponding risk assessments for the airshows from 2014 and 2013, consideration of the RAFA Battle of Britain Air Show Shoreham Airport Risk Assessment [5] (the ground risk assessment) from 2015, against the CAP 403 guidance from the Civil Aviation Authority (CAA) [4] and with Health and Safety Executive (HSE) and other risk assessment guidance [6]. The main findings from the review are:

- The risk assessment does not fully comply with the guidance given in CAP 403. Compliance with the industry guidance would be expected as a minimum.

- The 2015 Air Display Risk Assessment does not appear to have been finalised as only a draft version has been made available. A risk assessment should be properly documented and a record kept of changes made;

- The risk assessments from the previous years are almost identical to that for the 2015 airshow, with only minor modifications to two of the identified hazards assessed. According to the HSE guidance [6, 7, 8], risk assessments should be regularly reviewed, with a record of the review being made. The review should incorporate any additional knowledge gained since the previous review was undertaken. Additional information from the AAIB indicates that the risk assessment was sent to others for comments but there is no indication that additional knowledge was considered and not all of the legitimate concerns raised were incorporated into the document;

- The Civil Aviation Authority (CAA) guidance for organising and running airshows given in CAP 403 [4] has not been fully followed (e.g. the use of an alternative risk matrix which makes it harder to assess the effects of mitigation measures on the risk, not considering additional risk reduction measures for risks that fall into the "Acceptable" region of the matrix, etc.);

- There is no acknowledgement that the CAP 403 guidance was rewritten in February 2015, which may or may not impact on the risk assessment;

- The risk assessment does not comply with the guidance given by HSE for assessing that risks are being properly controlled and managed [6, 7] (e.g. there is no demonstration that the risks have been reduced ALARP);

- It is unclear how the hazards and appropriate mitigation measures have been identified, leading to a lack of confidence that all credible hazards and mitigation measures have been considered. A reference to a meeting where the hazard identification was undertaken, together with a list of attendees would be expected. The meeting would also consider risk reduction measures for the identified hazards. The outcome of this meeting would either be recorded directly in the risk assessment, or in another document with reference made to it from the risk assessment;

- There is no evidence that all relevant parties (e.g. representatives from the airfield, pilots, members of the Flying Control Committee (FCC), etc.) have been consulted on the risk assessment and provided input to it. A record of those involved in the identification of hazards and risk reduction measures should be included, together with their qualifications and areas of expertise;

- There appears to be no account taken of lessons learnt, from either previous airshows at Shoreham or elsewhere. HSE guidance [6, 7, 8] states that previous incidents should be considered as part of the risk assessment process;

- There appears to be no comprehensive review of the risk assessment each year, and there is little evidence that there was a comprehensive review of the assessment in 2015 compared to the previous year (the signatures are digitally scanned in the assessment document and so there is nothing to indicate that the person in overall charge viewed the risk assessment in 2015. Also, the date of the signature for the 2015 risk assessment is August 2015 although the date on the risk assessment is April 2015. The August date given for the signature in the 2015 assessment corresponds with the date given in the 2014 assessment). A regular review of the risk assessment to ensure that the hazards are still relevant, no new mitigation measures have been identified, etc, forms part of the guidance given by HSE [6, 7, 8]. The AAIB have obtained additional information that indicates that some form of review did occur prior to the 2015 airshow. The risk assessment was sent to others for comment but there is no indication that a comprehensive review process occurred, no record is made of this in the risk assessment, and there is one legitimate issue that has not been incorporated into the risk assessment;

- There is an error in the interpretation of what is required for risks that are considered to be "Acceptable". Both the CAA guidance [4] and the HSE guidance [6, 7, 8] state that risk reduction measures should be considered for risks that fall into this region and any that are assessed as being practicable should be implemented;

- Some of the risks identified have been wrongly classified as "Review" when they should be "Unacceptable";

- Some of the hazards have not been clearly defined; they are not hazards in themselves but could affect the consequences of an aircraft crash (e.g. the congregation of people along the A27 and other surrounding roads);

- The majority of the mitigation measures are taken from the code of practice. In most cases, additional specific mitigation measures have not been considered. HSE guidance [6, 7, 8] is clear that, as the risks increase, greater effort is required to identify additional mitigation measures over and above standard good practice, to reduce the risks. Many of the identified hazards at the Shoreham Airshow fall into the "Unacceptable" region of the risk matrix but very few additional measures have been assessed;

- Some of the mitigation measures apply only to military aircraft, when some civilian aircraft could also cause the hazard under consideration;

- There is no clear link between the mitigation measures and actions required and the reduction in the risk. Instead it is stated that all risks have been reduced to the "Acceptable" region. This is a recognised pitfall as given in an HSE paper [7];

- There appears to be no understanding of the need to reduce risks to ALARP (As Low As Reasonably Practicable), which does not mean that they must all fall into the "Acceptable" region. HSE guidance [6, 7, 8] requires the risks to be reduced ALARP and that the risks should be regularly reviewed to ensure that they are being managed effectively; and

- There is no demonstration that the mitigation measures reduce the risks ALARP.

Appendix J (Cont)

The majority of the mitigation measures identified are taken from CAP 403 guidance, and are therefore referring to a code of practice. However, there is no assessment as to whether these measures do reduce the risk levels of the hazard, and whether this is from a reduction in the likelihood, severity or both. An assessment of the impact of any mitigation measure should be considered as well as assurance that the mitigation measures are being correctly implemented.

Where there is a more significant risk then other measures should be identified to control and reduce the risks ALARP. This is especially true for features that were specific to the Shoreham Airshow, such as nearby population centres, weather conditions, and so on.

In conclusion, the risk assessment is not considered to be fit for purpose as it does not demonstrate that the risks from the air display at the airshow were being managed and controlled.

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Appendices

Appendix J (Cont)

HEALTH & SAFETY LABORATORY

The Health and Safety Laboratory (HSL) has been developing health and safety solutions for over 100 years. Our long history means that we're well-placed to understand the changing health and safety landscape, and anticipate future issues. We are part of the Science Directorate of the Health and Safety Executive (HSE) – our work with the regulator gives us a unique insight into the changing face of workplace health and safety.

HSL employs about 400 staff, who help make working environments and working lives safer, in the UK and around the world. From our base in Buxton, and with staff in six other locations across the UK, we focus on the development of practical solutions to workplace health and safety problems. Our scientists have a strong international reputation for world-class research, undertaken on behalf of the Health and Safety Executive (HSE) and other sponsors in government and industry.

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Health and Safety Laboratory
Harpur Hill
Buxton
Derbyshire
SK17 9JN
UK
www.hsl.gov.uk
T : +44 (0) 1298 218218
E : hslinfo@hsl.gsi.gov.uk

Appendices

Appendix K

Review of the Risk Assessment Sections of CAP 403

HEALTH & SAFETY
LABORATORY

Review of the risk assessment sections of CAP 403

20 June 2016
MSU/2016/13

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Derbyshire, SK17 9JN
T: +44 (0)1298 218000
W: www.hsl.gov.uk

HEALTH & SAFETY LABORATORY

REVIEW OF THE RISK ASSESSMENT SECTIONS OF CAP 403

MSU/2016/13

Report Approved for Issue by:	
Date of Issue:	**20 June 2016**
Lead Author:	
HSL Project Manager	
Technical Reviewer(s):	
Editorial Reviewer:	
HSL Project Number:	**PE06406**

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Appendices

Appendix K (Cont)

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SUMMARY

The Air Accident Investigation Branch (AAIB) asked the Health and Safety Laboratory (HSL) to assess the risk assessment sections of CAP 403, a document produced by the Civil Aviation Authority (CAA) which provides guidance on how to run an airshow, including information on considering the safety aspects of airshows. The AAIB would like to know if the guidance provided by the CAA is a suitable and sufficient aid to those managing the air display risks at airshows.

HSL is the science laboratory for the Health and Safety Executive (HSE). HSL provides scientific evidence to support HSE policy and regulation and provides expertise and advice for businesses both within the UK and internationally. The HSL risk assessment specialists therefore have extensive experience in assessing hazard and risk assessments from a regulatory Health and Safety perspective.

HSL reviewed CAP 403 to determine whether the guidance provided sufficient aid for airshow risk assessors considering the safety of air displays. The review considered whether any additional detail that could be included in the guidance would help inform the risk assessment process for airshow air displays. A number of points to consider as part of the review were identified following discussions between the AAIB and HSL. These were to assess:

- How the guidance describes the risk assessment process;
- How the guidance identifies those who should be involved in the risk assessment process;
- Whether the risk assessment guidance is applicable to all sizes of event;
- How the implementation of the risk assessment guidance allows risks to be managed;
- Whether the guidance adequately reflects health and safety legislation;
- Where there is risk assessment good practice outlined in the guidance; and
- How the guidance given in CAP 403 compares to other CAA hazard and risk assessment guidance.

A number of observations have been made of good practice in hazard and risk assessment in CAP 403. There are some areas of the guidance, however, where additional information is required to lead to greater confidence that a risk assessment created using the guidance will be suitable and sufficient for managing the risks. The people undertaking the risk assessments are likely to be experts in flying but not in risk assessments. There are several areas, therefore, where the inclusion of additional information for assessors might be beneficial.

The basic principles of risk assessment are covered in the CAP 403 guidance on the safety aspects of air displays at airshows. The guidance given is applicable to risk assessments in general. The focus of this study has been on the application of this advice to the assessment of the risks from the air displays planned at the airshows.

Appendix K (Cont)

This study has identified areas of the guidance where changes are required to give airshow flying display organisers the information needed to undertake meaningful risk assessments, or in some cases, to avoid misleading organisers on what needs to be done. Ultimately, these improvements should ensure that the risk assessments help airshow organisers to target and control the risks from flying displays.

- Identifying the right people to assess the risks

  CAP 403 should clearly list the qualifications and experience required of the people who should be involved in assessing the risks. This will ensure that people with sufficient knowledge to identify the hazards and the mitigation measures, and to assess the associated risks, will undertake the risk assessment;

- Improving guidance on hazard identification

  CAP 403 should include some additional information to stress the importance of the hazard identification process to the quality of the overall risk assessment. This could include advice on defining what is meant by a "hazard", and recommending that more information is provided in an assessment explaining the thoughts of the assessor behind the hazards identified.

  The CAP 403 guidance could also recommend that a record be kept of the hazard identification process. This allows an understanding of the expertise used by the personnel involved in the process and would allow an understanding of the reasons why some hazards have not been considered further in an assessment;

- Issues with the guidance on mitigation measures

  An area where the existing guidance in CAP 403 is potentially misleading is concerning the area of risk mitigation. This is a significant area that needs to be improved as failing to properly assess the mitigation measures could lead to inappropriate or unachievable measures being put in place that do not control or reduce the risks.

  The guidance uses examples where CAP 403 requirements to allow an airshow to go ahead are used as measures to mitigate the risks from the identified hazards. The guidance in CAP 403 should be taken as the minimum requirement and the risks assessed initially assuming that the guidance has been followed. Identified mitigation measures to lower the risk should go beyond those contained within the guidance.

  It should be explicitly stated that an explanation of how the identified mitigation measures lower the severity or likelihood classification in the risk assessment calculation should be recorded. Additional information on how to identify mitigation measures and assess the impact of the measures, together with revised examples should be included in CAP 403. CAP 403 should encourage assessors to demonstrate that the risks have been reduced As Low As Reasonably Practicable (ALARP) for the air displays; and

- Risk criteria review

  It is recommended that the tolerability of risk criteria currently provided in CAP 403 (i.e. the definitions of high, medium and low risk) are reviewed to assess whether these need to be modified. Risks are currently classified as high if the risk level is calculated to be above 15. Using this scoring system means that there are some high consequence events that are deemed "tolerable" for relatively frequent likelihoods. A review would clarify whether the criteria are acceptable or whether a change would be appropriate.

This study has also identified areas within CAP 403 where additional information or restructuring could help airshow organisers and risk assessors when assessing the risks.

- Location of the risk assessment guidance in the document

  Moving the risk assessment section out of the appendices of CAP 403 and into the main body of the document would raise awareness of the importance of generating a risk assessment. Detailed examples and additional information could be retained in appendices;

- Including the risk matrix as a visual aid

  The risk matrix should be explicitly included within the guidance to make it easier for an assessor to determine where the risks from an activity lie;

- Highlighting the need for regular reviews of the risks assessed

  Guidance should be provided on the need to regularly review the risk assessment, particularly for airshows that will occur more than once (e.g. annually). This provides assurance that any new risks introduced at a subsequent airshow are considered and managed, and also that lessons have been learned from previous airshows; and

- Guidance on reducing and controlling risks

  The guidance could clearly state that the risks from the airshow do not need to be reduced to a low risk level and can remain as medium risk, provided that it is demonstrated that the risks are effectively managed. This is to ensure that more significant risks are treated with the appropriate level of caution.

Some additional modifications to CAP 403 have been identified that would add further value to the document and potentially make it easier for airshow organisers and risk assessors to undertake assessments to control the risks.

- Clearly distinguishing the air display risks from other risks

  Specifying that the air display risk assessment and the ground based aspects should be separated in some way to distinguish between these different aspects of the airshow. This would ensure that those who need to be aware of the air display risks, and the measures to mitigate them, do not inadvertently ignore some of the risks through having the details of these risks and mitigation included with the risks from ground based activities;

- Making the glossary more accessible

  Moving the glossary to a separate section and including all risk assessment terms would aid the clarity of the guidance given to the people undertaking the risk assessment. Ensuring that the glossary is in alphabetical order would be of further benefit; and

- Clarifying risk assessment responsibilities

  Carrying out a risk assessment should be clearly listed as one of the requirements and responsibilities of the Event Organiser and the FDD. This will help emphasise the importance of the risk assessment, and who should be responsible for ensuring that a risk assessment is undertaken.

A search was undertaken to determine whether there was any suitable guidance for similar high hazard public events that could be used as part of a benchmarking exercise. This included Formula 1 racing, the Isle of Man TT and Speedway. No guidance was found for similar events that was suitable for benchmarking the risk assessment and safety aspects of CAP 403.

1 INTRODUCTION

At the Shoreham Airshow on 22 August 2015 a vintage jet aircraft crashed onto a nearby road, killing 11 people and injuring 16 others. The pilot was amongst those injured in the accident. The Air Accident Investigation Branch (AAIB) are undertaking the accident investigation to determine the causes of the accident and identify recommendations to avoid any similar occurrences in the future.

The AAIB asked the Health and Safety Laboratory (HSL) to assess the risk assessment guidance provided by the Civil Aviation Authority (CAA) for flying displays and special events. This guidance forms part of CAP 403 [1] and would have been used to help produce the risk assessment for the Shoreham Airshow.

As part of the Health and Safety Executive (HSE), HSL provides scientific advice on health and safety matters to the UK government and to businesses in the UK and internationally. The HSL risk assessment specialists have experience of reviewing hazard and risk assessments from a regulatory perspective across a range of industries and activities.

The aim of the review was to assess how well the guidance available at the time covered specific areas related to the risk assessment process. Other items to consider in the review were identified following discussions between the AAIB and HSL. The topic areas identified were:

- How the guidance describes the risk assessment process
  Assessing the way in which the guidance describes the risk assessment process for a potential risk assessor;
- How the guidance identifies those who should be involved in the risk assessment process
  Assessing the clarity of the guidance in determining who should be undertaking the risk assessment in terms of their qualifications and experience, and of anyone else that should be involved;
- Whether the risk assessment guidance is applicable to all sizes of event
  Assessing whether the guidance provides sufficient information for a risk assessor to assess both large and small events;
- How the implementation of the risk assessment guidance allows risks to be managed
  Assessing whether, if the guidance is followed in the production of a risk assessment, the risks will be managed adequately;
- Whether the guidance adequately reflects health and safety legislation
  Comparing the risk assessment guidance in CAP 403 to guidance produced by HSE [2], other published guidance [3, 4] and legislation [5];
- Where there is risk assessment good practice outlined in the guidance
  Identifying areas of good practice in the guidance with regard to risk assessment procedures, together with areas where improvements could be beneficial; and
- How the guidance given in CAP 403 compares to other CAA hazard and risk assessment guidance
  Comparing the risk assessment guidance in CAP 403 to the CAP 760 [6] guidance published by the CAA.

A search was undertaken to determine whether there was any suitable guidance for similar high hazard events that could be used as part of a benchmarking exercise. This included Formula 1 racing, the Isle of Man TT and Speedway.

The remainder of the report is structured as follows:

- Section 2 presents the findings of the work carried out during the review of CAP 403; and
- Section 3 presents the conclusions from the review.

2 REVIEW OF THE RISK ASSESSMENT ASPECTS OF CAP 403

2.1 OVERVIEW OF CAP 403

The 13th Edition of the CAA guidance document, CAP 403 [1] has been reviewed in this work. This is the version that was available at the time of the Shoreham Airshow in 2015.

CAP 403 is divided into two parts; the first part is aimed at flying displays and the second at special events such as air races, balloon events etc. There are twelve appendices that provide additional information and support to the main sections of the document. There is a revision history included in the document indicating that the13th Edition of CAP 403 represented a complete rewrite from the previous version. This version of CAP 403 was issued in February 2015.

Part A of CAP 403 is divided into 14 chapters, covering subject areas such as flying display legal requirements, personnel and preliminary planning, site and display management etc. Part B is divided into six chapters, each of which considers additional information required when considering specific special events such as air races, balloon events and model flying events.

This report is concerned with the guidance given on risk assessments. Only the sections of CAP 403 that are relevant to this review have been considered.

2.2 CAP 403 REFERENCES TO RISK ASSESSMENT

All references to risk assessment within CAP 403 have been identified and highlighted in order to determine what emphasis is placed on the need for risk assessment. The document contains a number of references to risk assessments, in relation to various aspects of the event being considered, indicating that all the risks relating to an event need to be properly assessed and managed. An outline of the structure of CAP 403 is provided in Table 1 in order to illustrate the location of each reference.

Table 1 Structure of CAP 403

Section	***Description***
Revision history	Details of this edition and the previous four editions.
General information	Brief introduction outlining the purpose of CAP 403, the background to it, and a glossary of terms.
Part A	
Chapter 1	Detailing the legal requirements for running an airshow.
Chapter 2	Details of the personnel required to run the show, and a brief description of what is required for the preliminary planning stage.
Chapter 3	Management of the site and display for the airshow.
Chapter 4	Description of what is required in terms of liaison with the CAA, Local Authority and the Emergency Services.
Chapter 5	The competencies required of a pilot displaying at the airshow.
Chapter 6	The skill levels required for different types of acrobatic displays.
Chapter 7	Guidance concerning formation flying.
Chapters 8 to 14	Guidance for ballooning, parachuting, banner towing, foot-launched aircraft, model aircraft and air racing as part of a flying display, and twilight and airborne pyrotechnic displays.
Part B	
Chapters 1 to 6	Guidance for special events covering air races, ballooning, fly-ins, rallies, helicopters, gyroplanes, model flying events and microlights.
Appendices	
Appendix A	Guidance on how to carry out a risk assessment.
Appendices B to L	Guidance covering other aspects of the event such as verbal and telephone briefings, deadlines for organisers, notification forms etc.

CAP 403 contains an initial, introductory section entitled "General information". Paragraph 1.3 in this section makes it clear that participating in or organising either flying displays or special events "carries a heavy responsibility". It is stated that "[s]afety is paramount" and this applies to participants and spectators, both those that are paying and those that are not. The paragraph continues "[d]isplays must be carefully planned both on the ground and in the air and nothing should be considered without careful thought to ensure that it is safe. A risk assessment procedure is included to help in the process".

The introductory paragraph makes it clear that the safety of everyone concerned with a flying display or special event must be carefully considered. This reflects general health and safety practice i.e. the importance of ensuring the safety of people affected by an event.

The guidance does not explicitly mention others in the vicinity of the flying display or special event who are not spectators but who could also be impacted should an incident occur (e.g. local populations). This may be something that could be considered an implicit consideration, but it might make it clearer for a person undertaking a risk assessment if this was explicitly mentioned in the guidance as something to be taken into consideration when assessing the risks.

The paragraph in CAP 403 states, with regard to the planning process to ensure that the event is safe, that "[a] risk assessment procedure is included to help in this process". A risk assessment forms an integral part of the safety procedure as this informs the organisers of the mitigation and control measures to control and reduce the risks from the hazards identified. Therefore, a slight change in the wording of this sentence would make it clearer that a risk assessment procedure should form part of the safety process and not just a ‘help’ to it. This would prevent any misunderstanding about whether there is the need for a risk assessment.

Chapter 3 in Part A of CAP 403 is concerned with the management of the site and the display. Paragraphs 3.30 to 3.32 consider overflight of spectators. Paragraph 3.31 states that permission may be granted for overflying of spectators by established formation teams of four or more similar powered fixed wing aircraft, provided they are supported by a comprehensive risk assessment that must be updated annually. This indicates that the overflying of spectators could be considered especially hazardous and that it therefore requires special consideration before permission will be granted.

It is not made clear if this risk assessment is to be carried out by the participants of the display, or by the organisers of the event. It might aid the guidance if it was made clear that ultimately the show organisers are responsible for ensuring that all the risks are properly assessed and managed. Including some clarity on the legal responsibilities of each of the key roles at the event may help in this process. It could be of use if guidance was given on the type of experience required by a person carrying out a risk assessment, in order to make it easier for the organisers to find the appropriate person/people for the task.

Paragraph 3.32 says that “[a]ircraft carrying parachutists may overfly the spectators’ enclosures or car parks whilst positioning to drop …”. No mention is made of a risk assessment in this instance, however, which appears to be an inconsistency with the requirement to have a risk assessment for other forms of overflight. If there are valid reasons for not requiring a risk assessment in this case, then a brief outline of the reasons could make it clearer for the people running the airshow.

Chapter 4 in Part A of CAP 403 is concerned with liaison with the CAA, the Local Authority and the Emergency Services. Paragraph 4.41 states the requirement for a suitable and sufficient risk assessment for all contractors and emergency services working on the airfield or in the adjacent areas. The risk assessments should “contain specific mitigation for dealing with any aviation materials which could become unstable following an accident”.

Paragraph 4.46 in Chapter 4 is entitled “Risk assessment” and states that “[r]isk assessment is an essential element of the production of any safety plan”. It says that a simple procedure is given in Appendix A that should be suitable for most flying displays and special events. The guidance continues by stating that “other alternative systems can be equally effective” and that advice on risk assessment can be obtained by contacting the CAA GA (General Aviation) Unit. A link is provided from the electronic version of CAP 403 to the email address of the CAA GA Unit.

For the benefit of people not viewing the electronic version of the document, it could be beneficial to explicitly include the CAA GA Unit contact email address in the document.

Paragraph 4.49, under “The Police” section, refers to the “event risk assessment” and, in particular, to the likelihood of criminal activity or disorder. It is implied that this risk assessment is different from the flying display risk assessment.

Under the “Fire and Rescue Service” section in Chapter 4, paragraph 4.54 states that there must be adequate facilities on site to respond to any fire or rescue emergency. It further states that aerodromes “may have dedicated trained staff available; the degree to which these need to be augmented will be dictated through the risk assessment”.

Paragraph 4.60, under the "General" section of Chapter 4 mentions the use of hazardous materials and states that "[i]nformation on such hazards should be included in the risk assessment".

The main risk assessment guidance is contained in Appendix A of CAP 403, which is discussed in the subsequent sections.

2.2.1 Observations

There is some ambiguity as to whether there needs to be an overall risk assessment undertaken covering all aspects of the event, or whether there should be a number of assessments covering specific areas. In reality, different approaches may be appropriate for different sizes and types of airshow.

It does seem sensible to at least undertake a separate air display risk assessment from other ground based activity assessments. The air display assessment findings could be referenced in the general risk assessment or in an overarching assessment document for larger airshows. The benefits in doing this are that people with the relevant experience could be involved in the individual risk assessments, rather than the same people trying to identify hazards that are outside their area of expertise. It also makes it easier for a worker who has not been involved in the development of the risk assessment to absorb the parts of the document that are relevant to themselves. It might be beneficial for the guidance to explicitly make this point.

The guidance given in Appendix A can be applied to all aspects of an event. If more than one risk assessment is expected (which is likely at large events where there may be a wide variation in the types of risks that will need to be assessed), a brief description of what each risk assessment is expected to cover could be useful.

A description of the experience and knowledge required of people who are producing the risk assessments should be provided. This would aid the event organisers, who have overall responsibility for safety, in assigning the task to an appropriate person/appropriate people, if they are not undertaking it themselves.

CAP 403 does contain a glossary explaining many of the acronyms and terms in use in the document. However, the glossary forms part of the introductory "General information" section and is not in alphabetical order. This makes it more awkward to find terms when reading the document. It also does not include specific risk assessment terms, or provide a reference of where to find this information. A distinct, alphabetic glossary of all terms used within CAP 403 could aid comprehension and remove the potential for ambiguity and misunderstandings.

In paragraph 2.23 of CAP 403, under the title "Preliminary planning", a list is given of items that the Event Organiser and the Flying Display Director (FDD) need to consider. The FDD is the person responsible to the CAA for the safe conduct of the flying display. A risk assessment does not form part of the list of requirements for the organisers and the FDD. As these are the personnel ultimately responsible for the safe running of the airshow then the risk assessment and implementation of risk controls should be specified amongst the requirements and responsibilities of the Event Organiser and the FDD.

Key point

The qualifications and experience required of the people undertaking the risk assessment should be clearly identified.

2.3 GUIDANCE ON HOW TO UNDERTAKE A RISK ASSESSMENT

The review considered whether the risk assessment guidance provided by CAP 403 describes the risk assessment process in enough detail. This is seen as an important point to consider as it is assumed that most assessors are unlikely to be risk assessment experts, rather being experienced pilots and people familiar with organising airshows. This does mean they should have the experience and knowledge to identify appropriate hazards and mitigation measures. However, a lack of understanding of assessing risks might mean this knowledge and experience is not being captured properly.

Appendix A in CAP 403 provides some guidance on how to undertake a risk assessment. It is only referred to from paragraph 4.46 in the main body of the document, although risk assessments are referred to from elsewhere in the document.

Appendix A outlines why risk assessments are needed. It states that a risk assessment does not need to be complicated and that the procedure given should "suit the needs of most flying display[s] and Special Events". It is stated that other alternative systems can be equally effective and that the CAA GA Unit can be contacted to provide further advice. A link is provided to the email of the CAA GA Unit from the electronic version of CAP 403. As in the case of the link provided from the main body of the guidance, it could be beneficial to explicitly include the email address for those people viewing a paper copy of the document.

The Appendix provides a definition of the risk as the severity of the hazard times the likelihood of occurrence. The five steps to risk assessment that are defined by the HSE are referenced and an outline of the five steps given as:

- Step 1: Identify the hazards associated with activities contributing to the event, where the activities are carried out and how they will be undertaken;
- Step 2: Identify those at risk and how they may be harmed;
- Step 3: Identify existing precautions;
- Step 4: Evaluate the risks; and
- Step 5: Decide what further actions may be required, i.e. mitigation.

It is stated that Step 4 will involve a combination of the likelihood and severity of the identified risk.

The five steps in CAP 403 have a slightly different emphasis than the risk assessment guidance available on HSE's website [7]. From the website, the five steps are given as:

- Step 1: Identify the hazards;
- Step 2: Decide who might be harmed and how;
- Step 3: Evaluate the risks and decide on precautions;
- Step 4: Record your significant findings; and
- Step 5: Review your assessment and update if necessary.

The five steps in CAP 403 are effectively encapsulated in Steps 1 to 3 of the HSE guidance. The requirement to record the findings applies to employers with five or more employees, although it is recommended that a record is made in all cases. Step 5 of the HSE guidance is captured in the last paragraph of Appendix A of CAP 403, rather than within the five steps. It may be beneficial to move this statement to one of the five steps as this provides an indication that it is an integral part of the risk assessment process. Recording the process lends confidence to the conclusions reached (i.e. that the risks are being properly managed).

The guidance does not mention reviewing the risk assessment and updating the assessment if required. This forms an integral part of the risk assessment process. It allows the risk assessor to evaluate how effective the control measures are and to determine whether more needs to be done. This can be an iterative process, even for events that are one-off. For events that are not one-off, any existing risk assessment should be reviewed prior to each event to ensure that it is still suitable and sufficient and to incorporate any additional information that has become available since the previous risk assessment.

In paragraph A5 of CAP 403 it is stated that the assessment of the likelihood and severity of a hazard is “subjective” and is “based on personal experience of the activity under assessment or statistical evidence when available”. Lessons learnt from previous airshows can aid the process, together with the experience gained by people over the years.

Paragraph A6 makes it clear that the assessment needs to be carried out by someone who is aware of the risks being assessed and who will use “sound judgement” in the preparation of the risk assessment. The document notes that the risk assessment process could be subject to challenge in the event of an incident.

Paragraphs A5 and A6 in CAP 403 make it clear that the assessor needs to have a firm understanding of the risks being assessed. This is an important point to make as it means that there is a greater likelihood of all the hazards and appropriate mitigation measures being identified. However, CAP 403 does not give any examples of the type of qualifications and experience that a risk assessor would be expected to have. Including this information would be beneficial in terms of clarifying who should undertake the risk assessment. It is generally good practice to include within the risk assessment a record of those that were involved in the process, together with their qualifications and experience. This could be added as a requirement to the risk assessment section in CAP 403 to further improve the guidance being provided.

Paragraphs A7 and A8 of Appendix A in CAP 403 provides a list of the headings that should be used for the severity and likelihood classifications as part of a risk matrix. Numerical values are given for each category that can be used to provide a risk rating by multiplying the severity and likelihood values together. The severity classifications are reproduced in Table 2 and the likelihood classifications in Table 3.

Table 2 Severity classifications in CAP 403 [1]

Trivial	*Minor injury*	*Serious injury*	*Single fatality*	*Multiple fatalities*
1	2	3	4	5

Table 3 Likelihood classifications in CAP 403 [1]

Highly unlikely	*Possible*	*Quite possible*	*Likely*	*Highly likely*
1	2	3	4	5

One suggested area for improvement is the likelihood classifications. It is recognised that the assessment is necessarily subjective but it would be beneficial if additional wording around the classifications could be included to give a clearer idea of what frequency is associated with each term. It could also be stated that the risk assessor can determine what the classifications mean for their event and that they record their assumptions. This could aid future assessors and also their own development.

An example of how to use the severity and likelihood classifications is given in a table at paragraph A9 of Appendix A in CAP 403. It is reproduced in Table 4. CAP 403 clearly states after the table that it is used for example only and that it "does not imply or infer a risk level" i.e. the examples given do not represent an actual risk assessment but provide an indication of how to carry out a risk assessment.

Table 4 Example of using the risk scores from CAP 403 [1]

Hazard	*Severity*	*Likelihood*	*Rating*	*Mitigation*	*M/factor*	*Final rating*
Aircraft accident involving crowd casualties	5	3	15	Adhere to separation distances; ensure crowd remains inside crowd line	Likelihood reduced to 1	5
Fire in exhibition area	3	3	9	Provision of First Aid Fire Fighting facilities	Severity reduced to 2	6
Terrorist activity	5	2	10	Close, early liaison with police	Likelihood reduced to 1 through planning	5

The first hazard identifies that people could be harmed. This is useful because it makes it clear that it is the risk of people being harmed that is being assessed. However, this entry does not give a location for where these people could be harmed, which is not useful because it makes it harder to determine the likelihood of the incident occurring and also to identify suitable mitigation measures. The other two examples in the Table reproduced from CAP 403 do not explicitly state that people could be harmed, although it is implied in the severity ratings used. These two entries do not state who would be harmed i.e. the public, participants, staff or a combination of all three.

In terms of the example mitigation measures given in the table, they are taken from the main body of the guidance. It would be expected that the guidance should be followed as a minimum and so these measures should be carried out anyway. The assessment should be carried out with the assumption that these measures have been incorporated and the mitigation column should only contain additional measures required to reduce the risk further. This means that, in terms of the examples given in Table 4, the mitigation measures listed are not actually mitigation measures and should have no impact on the risk rating. This point should be clearly stated in the guidance. Examples of the types of additional measures that may be considered should then be given in CAP 403.

Table 4 has a column describing the mitigation measure and another showing the revised likelihood or severity rating, together with the final risk rating. This is very useful and links the mitigation measure with the reduction in risk. The examples of mitigation given, however, do not directly explain why the severity or likelihood is reduced.

A general explanatory guidance note could be given in CAP 403 stating that an explanation should be given as to why a mitigation measure reduces the likelihood and/or the severity for each identified hazard. The examples would aid assessors when making their own assessments.

Using the examples given currently in CAP 403, an additional sentence in the mitigation column would be beneficial to illustrate this point e.g. in the first example concerning crowd casualties following an aircraft crash, a sentence explaining that the mitigation measures limit the number of places that the public will be located leading to a lower likelihood that an aircraft will crash into these public areas makes it clearer why this mitigation reduces the risk level.

A sentence in CAP 403 explaining that who is at risk should be identified and where they are likely to be located in order to make this connection could be of use. Providing more detail in the "Hazard" column of the example table could also be beneficial to help illustrate this point.

Paragraph A11 defines a risk with a rating of less than 6 as low risk, a risk with a rating of between 6 and 15 as medium risk, and a risk with a rating higher than 15 as high risk. The use of likelihood and severity scores to calculate a risk rating allows a risk matrix approach to be adopted.

The risk matrix that would be generated by the use of the severity and likelihood classifications and the definitions of low to high risk is not included in the document but can be constructed from the other information given. A risk matrix is a matrix of severity against likelihood and indicates where risks are broadly acceptable, tolerable if controlled sufficiently, and unacceptable. The inclusion of the risk matrix could be beneficial to those undertaking the risk assessment. It would help assessors to know where the risk falls and hence provide an indication of how much effort is required to reduce the risk. It would also aid in showing whether the mitigation measures given are sufficient. This information is given in the various paragraphs in the Appendix but a visual aid could improve the clarity for a potential assessor. An example of what the risk matrix would look like, based on the information given in CAP 403, is shown in Table 5.

Table 5 Example risk matrix

Severity	*Likelihood*				
	Highly unlikely	*Possible*	*Quite possible*	*Likely*	*Highly likely*
Trivial	1	2	3	4	5
Minor injury	2	4	6	8	10
Serious injury	3	6	9	12	15
Single fatality	4	8	12	16	20
Multiple fatalities	5	10	15	20	25

The colour coding reflects the tolerability of risk by indicating areas of unacceptable risk (red), areas that are tolerable provided the risks are appropriately managed (yellow), and areas of broadly acceptable risk (green), or high, medium and low risk using the terminology in CAP 403. The different areas provide the assessor with an indication of the level of effort required to reduce the risks. It also aids in the assessment of how beneficial a risk reduction measure is, and whether it is sufficient at reducing the risks (e.g. if a risk falls into the red box with a rating of 20 and a measure reduces it to 16, the matrix indicates that the risk is still intolerable and more must be done to reduce the risk).

It could be argued that the risk matrix given in CAP 403 is not cautious enough when considering the likelihood of some of the more severe consequences. A more conventional matrix would code risks with a rating of 5 as tolerable i.e. in the yellow region, and risks rated as 15 as unacceptable i.e. in the red region. As it stands, a hazard that is "quite possible" and that can cause multiple fatalities sounds like it is something that can occur fairly frequently and hence should be in the unacceptable region of the matrix, whereas it currently falls into the tolerable region. The same is true of a hazard that causes serious injury and is "highly likely". It is possible that, if the matrix had been reproduced as in Table 5, then it may have been decided to adjust some of the classifications.

The remaining paragraphs in Appendix A of CAP 403 state that attempts should be made to reduce the risks, even when the risk is low. It also states that high risk ratings are generally unacceptable and that risk reduction measures should be sought to reduce the rating to medium or low risk. This represents accepted good risk assessment practice, as provided in guidance by HSE (e.g. [2]).

A risk assessment should be able to demonstrate that the identified mitigation measures have reduced the risks As Low As Reasonably Practicable (ALARP). The Health and Safety at Work etc. Act, 1974 requires duty holders to ensure, So Far As Is Reasonably Practicable (SFAIRP), that their activities do not expose the public to health and safety risks. The Health and Safety Executive (HSE) considers this requirement of the Act to be met if the duty holder reduces the residual risks As Low As Reasonably Practicable (ALARP). Risk assessors may find text explaining the process constructive, which could include text for both hazard identification and for the assessment of mitigation measures.

One important point regarding risk assessment that does not come across clearly in CAP 403 is that the effort required to undertake a risk assessment should be proportionate to the risks being considered. This applies both in terms of the scale of the event being assessed, and in terms of the individual hazards that are identified. In particular, it would be expected that a large airshow, for example, with a number of different displays and types of participating aircraft and with a significant number of spectators, will require more consideration than a much smaller event where far fewer people and aircraft (which includes balloons, microlights etc.) will be involved.

Similarly, a hazard that has been identified as having a medium to low risk will require less consideration than one that has been identified as having a high risk (although, as has been made clear in CAP 403, mitigation measures should be considered even for low risk hazards).

The examples given in Table 4 imply that one risk assessment will be undertaken for all hazards associated with an event, whether they are caused by events occurring in the air (e.g. an aircraft crash), or by incidents occurring on the ground (e.g. fires in catering areas). This is generally acceptable for small events but, at large events where there are a significant number of potential hazards, it may be beneficial to undertake a separate air display risk assessment. This may make it easier to read and understand by those who are helping/working at an event and who are likely to be assigned to specific tasks. It could be beneficial to extend this advice to all sizes of event.

An advantage of having separate risk assessments for different aspects of the show is that the people with a particular area of expertise can be involved in helping develop the risk assessment that is pertinent to their knowledge (e.g. people with flying expertise can help with a risk assessment looking at the hazards from flying displays, those with expertise in running ground based activities can be involved in identifying the hazards from catering, car parking etc.). Some guidance on this could be provided in CAP 403, noting that a single risk assessment for a small event with few hazards might be sufficient but that a separate air display risk assessment may be preferable.

A risk assessment can be informed by incidents that have occurred previously, either at the event under consideration, or at similar events. This can aid in the identification of the hazards and the risk associated with them. It may also aid in the identification of any suitable mitigation measures.

Incidents at an airshow, even near misses that have not caused an accident or instance of ill-health, should be recorded in order to learn from them at future events. It could be beneficial to include a paragraph in CAP 403 to make this point.

A risk assessment is a living document and should be reviewed regularly. This may mean that an existing document is reviewed prior to each event, or that it is reviewed during the event if additional information becomes available (e.g. a mitigation measure has been shown to be particularly beneficial and it can be applied to other aspects of the event, or an incident has occurred at the event). A review after the event can also be of value in helping identify aspects that went particularly well or risks that were not so well managed. A record of the review process should be kept. It would be useful to mention this aspect of the risk assessment process within Appendix A, but noting that this will be of less value for a one-off event. Any lessons learnt could be applied at other events, however.

The final point made is that organisations should “record and retain the details of their risk assessment process”. This is an important point and it may be beneficial to incorporate it as part of the “five steps”, as suggested by HSE. Moving this statement to earlier in the document (or repeating it at an earlier stage) may help to ensure that assessors are aware of the need to keep a record of the process that they have undertaken to assess and manage the risks.

2.3.1 Observations

Appendix A of CAP 403 provides some useful information for potential risk assessors, and does provide guidance on how to undertake a risk assessment, including the use of a risk matrix and the need to try and reduce all the risks, even those that are assessed as being low. There are some areas that could potentially be improved by providing additional information, however. Some of these have been identified in the discussion above and are summarised here.

Moving the risk assessment guidance into the main body of the document rather than the appendices might be a useful modification. This would highlight the importance of undertaking an adequate risk assessment. Any additional detail and examples could be kept in the appendices for the sake of brevity in the main sections.

More guidance is required on how to identify the hazards, including how to record the process and who was involved. Guidance could be given on the qualifications and experience required of people undertaking the risk assessment.

Part of the hazard identification process is also to identify any mitigation measures that can be used to lower the risk. These should be recorded and each one assessed to determine how effective the measure is at controlling the risk. A measure may be discounted for valid reasons (e.g. it would be costly/problematic to implement and has a minimal effect on the risk), but a record should be made of the reasons for not considering it further.

Providing text to explain the ALARP process may be constructive. This could include information on hazard identification and the assessment of mitigation measures.

As has already been discussed in Section 2.3, the likelihood phrases used in the risk matrix are open to interpretation. It would be beneficial if the guidance provided an additional description around each term and/or suggested that the risk assessor provides a clear definition of the likelihoods and records their definition in the risk assessment.

In order to accurately assess the severity associated with a particular hazard, it may be of use to suggest that maps of the surrounding area are included. These can show areas of local population and areas where people may congregate, together with sites that could lead to an escalation in severity should an accident occur (e.g. industrial chemical sites). The maps may also indicate the areas over which the aircraft, balloons, microlights etc. are permitted to fly, and at what heights. These may aid the assessor in determining who is at risk and also in the severity classification.

Explicitly including the risk matrix, using colour coding to indicate where the risks are acceptable, tolerable if managed sufficiently, and unacceptable, would aid readers of the guidance in understanding the accepted tolerability of risk. It may be of value to the risk assessor in determining where the risks from a particular hazard lie and how effective the mitigation measures are at reducing that risk.

The guidance currently implies the use of a single risk assessment to cover both ground hazards and air display hazards. It could be beneficial to suggest that these are separated into two documents, particularly for larger displays.

The guidance given in CAP 403 does not provide a link between the mitigation measures and the reduction in severity and/or likelihood. Information could be provided on this point, with appropriate examples.

Key points

The risk assessment guidance should be moved into the main body of the report.

More guidance should be provided on the hazard identification process.

More information is required to aid assessors in identifying suitable mitigation measures and assessing that these measures are appropriate and are achievable.

The risk matrix should be reviewed to determine if the acceptable risk levels are appropriate.

2.4 GUIDANCE ON WHO SHOULD BE INVOLVED IN THE RISK ASSESSMENT PROCESS

The review considered whether CAP 403 provides guidance on who should be involved in the risk assessment process, and if the responsibilities of the organisers are clearly defined.

In Chapter 2 of Part A of CAP 403 [1] definitions are given of the people responsible for the running of the event. These are listed as:

- The Event Organiser who assumes overall responsibility for the event. "Responsibility for particular aspects … should only be allocated to people with the relevant experience and, if applicable, licences". It is inferred that the Event Organiser determines who takes on responsibility for each aspect of the event;
- The Flying Display Director (FDD) is "the person responsible to the CAA for the safe conduct of the flying display". The FDD must be suitably experienced in "all matters relating to flying in general and flying displays in particular". The FDD is "responsible for flying discipline generally, control of the flying display programme and cancellation or modification to the programme". At a small display (up to 3 items), the FDD may be a pilot of a participating aircraft. At a medium display (up to 6 items), the Event Organiser and FDD may be the same person although it is recommended that they are kept separate. At larger displays (7 or more items), the FDD should not take part in any other part of the flying display and should not be the Event Organiser; and

- The Flying Control Committee (FCC). At larger events (7 or more display items) it is recommended that a FCC is formed to provide assistance to the FDD. The FCC "should, wherever possible, comprise pilots with experience on the types of aircraft being flown at the flying display". It is also expected that members of the FCC "hold, or have held, a civilian [Display Authorisation] DA, or they should have extensive military flying display experience".

Details are also given of other officials responsible, for example, for supervising the parking of aircraft and cars, and of the flight crews involved in the displays.

Under the "Preliminary planning" section at paragraph 2.23 of CAP 403, a list is given of the items that need to be considered by the Event Organiser and the FDD. This list does not currently include a risk assessment. Including a risk assessment in this list would emphasise the importance of undertaking a risk assessment to the event organisers.

Paragraph 4.41 of CAP 403 makes it clear that the Event Organiser is responsible for the production of a safety plan. It continues by saying that "[s]uitable and sufficient risk assessments must be produced and circulated to all contractors and emergency services working on the airfield or adjacent areas used for the Air Show and associated displays." It is not made clear whether the Event Organiser is the person who should be carrying out these risk assessments. It also is implied that these are separate risk assessments from the event risk assessment, or, at least, that they form a separate part of the event risk assessment.

In Appendix A of CAP 403, which provides the guidance on how to undertake a risk assessment, paragraph A6 states that the assessment process "must be undertaken by someone who is aware of the risks associated with the activity being assessed and who will use sound judgement in the preparation of the assessment". There are no details given of the qualifications and/or level of experience required of the person who is carrying out the assessment. Including some examples of suitable experience or skills could aid the Event Organisers, or the FDD, to determine who is best placed to carry out the assessment.

Although not directly related to risk assessment, Chapter 3 of CAP 403 is concerned with the site and display management and Chapter 4 considers liaison with the CAA, Local Authority and Emergency Services. In both of these chapters it is not always made entirely clear who has responsibility for undertaking the required tasks, although it generally appears to be either the Event Organiser or the FDD.

2.4.1 Observations

There is only limited information provided in CAP 403 on who should be involved in the risk assessment process. This process includes hazard identification, mitigation measure identification and assessment, recording and reviewing etc. It is appreciated that the guidance cannot explicitly prescribe who should be involved, but it might be useful to include some guidelines on the experience and qualifications that would be expected for the people undertaking the assessment (e.g. flying experience, airshow experience, risk assessment experience and so on). Explicitly asking for this information to be recorded in the risk assessment would also be of value in the guidance.

The main area to improve in terms of responsibility for the organisation of the air show or other event is to either clearly state who should be responsible for each aspect of the event, or to suggest that the Event Organiser has ultimate responsibility and therefore needs to appoint people to cover each aspect. Records should be kept of who was involved with each task or activity. By not specifying responsibilities there is the danger that different people will assume that someone else is dealing with a particular issue. This might mean that a particular task is neglected or ends up being rushed in the end. Explicitly specifying the responsibilities ensures that all the guidelines are complied with and that there is no ambiguity as to individual responsibility. It also ensures that tasks are carried out to a high standard by appointing those who have the right background to make important decisions and judgements. This is of particular importance for risk assessments.

2.5 GUIDANCE FOR DIFFERENT SIZES OF EVENT

The review considered whether the guidance provided by CAP 403 can be applied to all sizes of events. For example, is the guidance sufficient for large events with a greater number of associated hazards, or is the guidance overly complicated for small events?

Chapter 2 of CAP 403 defines the roles of the Event Organiser and Flying Display Director of a flying display or special event. Guidelines are provided as to whether the roles can be combined, depending on the size of the event. Additional guidelines are provided as to whether these people can also take part in the event, which again depends on the size of the event. At larger events (7 or more display items) the use of a Flying Control Committee is recommended, in order to help the FDD.

Most of the information and guidance contained within the individual chapters of CAP 403 applies for all sizes of events (e.g. ensuring the site is suitable for the aircraft, that spectators are kept at a distance from the aircraft, that the pilots have the correct authorisations etc.). Where differences do occur (e.g. the use of radio communication is not required at small events), statements are made to exclude certain sizes of events. It should be noted that some aspects of the guidance will not be relevant for some types of event, both large and small (e.g. not all events will have pleasure flights).

In terms of the guidance on risk assessment, paragraph 4.46 implies that a risk assessment is required for all types and sizes of event, as would be expected. In Appendix A, however, there is nothing to indicate that greater consideration may have to be given to larger events. Compared to the smaller events, large airshows are likely to have a greater number of hazards and potentially more serious hazards and higher consequences (e.g. due to larger crowds, more aircraft displays, more complex displays etc.). The risk assessment needs to be proportionate to the risks being considered. Appendix A of CAP 403 provides generic advice for all airshows. This is not an issue in itself, as the same processes should be applied in all cases. This may mean, however, that a risk assessor does not apply the required amount of consideration and rigour to larger events.

The example table given at paragraph A9 of CAP 403 and reproduced in Table 4 contains three examples of hazards, only one of which is related to the flying aspects of the event. It is technically acceptable for all types of hazard, both ground based and air based, to be dealt with within one table and within one risk assessment for smaller events. For larger events, however, it would be beneficial to produce a separate air display risk assessment. This allows a small group of suitably qualified people to be involved in the identification of the hazards specific to their area of expertise, rather than having a large group of disparate people identifying a broader range of hazards. Guidance could be given within Appendix A, with additional example tables provided. The guidance could state that it is also preferable to provide a separate air display risk assessment at smaller events.

Carrying out separate risk assessments for the air display and for the ground based activities of the airshow allow the relevant risks to be assessed by the personnel involved in those particular areas and with the appropriate experience and skills. If a single risk assessment is used to assess all the airshow risks then there is a danger that not all parts that are pertinent to a person’s role will be obvious i.e. because so much of the risk assessment will not be relevant to them, they do not notice all parts that are relevant, or key parts of the assessment end up being undertaken by people with insufficient experience to fully understand the hazards.

The methods used to determine if a risk is being suitably managed do not differ significantly for the different sizes of event. In all cases, scenarios that are identified as having a high risk require greater consideration than those identified as having low or medium risk. In addition, the risk assessment process should be recorded for both large and small events. HSE guidance states that this is not a requirement, only a recommendation, for employers with fewer than 5 employees. Whilst there is a chance that small airshow events may technically fall into this category, it would be good practice for all airshows to record this information due to the significant impact of hazards to third parties from the airshow activities.

2.5.1 Observations

The general guidance on risk assessment provided in CAP 403 is generic and equally applicable to both large and small events. Additional clarity around the effort required for the different scale of events, however, could prove beneficial to the risk assessor to ensure that the effort expended is proportionate to the risks being assessed.

The examples given in the guidance indicate that all the identified risks can be assessed within the same table. The guidance should suggest that the risk assessment is split into separate sections covering different aspects of the event, where the air display risk assessment is undertaken separately.

2.6 MANAGEMENT OF RISKS USING THE GUIDANCE

Sections 2.3 and 2.5 discuss the risk assessment guidance given within CAP 403 Using this guidance as it stands, could an assessor develop an air display risk assessment that controls and reduces the risks “As Low As Reasonably Practicable” (ALARP) for the air display?

In order for risks to be ALARP, all mitigation measures that are not disproportionate in terms of cost or practicability should be applied, noting that higher risk scenarios will require a proportionally greater consideration of mitigation measures than lower risk scenarios. The higher the risk level, the more that is expected to be done to control or reduce the risk.

If the CAP 403 guidance is followed, it is not entirely certain that the hazard identification process will be recorded sufficiently. Although the guidance does state that the assessment process “must be undertaken by someone who is aware of the risks associated with the activity being assessed” and also, on a later page, that the risk assessment process should be recorded, it is not made completely explicit that a number of details should be recorded. This recorded information should include the people involved in the hazard identification, their experience and/or qualifications, and the identified hazards (including some reference to hazards that are later deemed to be unrepresentative for the event in question). Lack of detail in this area could lead to a lack of assurance that all potential hazards have been identified.

The severity and likelihood classifications used to assess the risks are adequate although the likelihood categories could be considered to be ambiguous. Additional guidance could be provided to allow assessors to determine their own definitions, provided they are recorded in the risk assessment (see Section 2.3.1for more detail) and/or additional wording could be used in the guidance to provide a clearer definition. Assuming that the correct severity and likelihood categories are allocated to each hazard, then there can be a reasonable level of confidence that the initial assessment of the risk is suitable, given the definition of low, medium and high risk level given in paragraph A11 of CAP 403.

The tolerability of risk criteria used to define high, medium and low risk may need to be investigated and possibly revised (e.g. a hazard that can cause multiple fatalities and that is "quite possible" is defined as being tolerable or medium risk). This uncertainty over the risk criteria can lead to uncertainty that the risks have been correctly classified.

If the example table given in paragraph A9 of CAP 403 is used as a template, there is some uncertainty that the hazard will be clearly described. To illustrate this point, the second example given in the table is a "[f]ire in exhibition area". It is not made clear who would be affected by this hazard, specifically where these people are located, or how many people have the potential to be affected. No explanation is given as to the choice of severity classification for this hazard, which is given as 3 (serious injury). It is unclear why the severity rating is not higher, as a fire can potentially cause death. Using the example as it stands could lead to uncertainty that the hazard has been correctly classified.

Including an additional description to this example explaining who could be affected, in what area and why the severity level has been selected could improve the understanding of the assessment and an appreciation as to how the mitigation measures apply to reduce the risks from this hazard. This is not a large amount of additional information and this information is necessary to identify how and where mitigation can be used to control the risk. If this information is not included then there is a concern that this is being treated as a paper exercise as the mitigation controls are listed but it is not clear how these would be implemented.

If a person undertook a risk assessment following a similar format to this example, then there would be uncertainty around how the hazard has been classified and to whom the risk applies.

A good point from the example table at paragraph A9 is that it is clear to see how the initial risk rating has been derived, assuming that there is confidence in the severity and likelihood classifications. It is also clear how the final risk rating is calculated, assuming that the reduction to either the severity or likelihood classification is accurate.

There are potential issues, however, with the mitigation and multiplication factor columns, which could lead to concerns with the overall assessment. Although the process itself appears satisfactory (i.e. identify mitigation measures, assess how these affect the likelihood or severity, and then calculate the final risk), in the examples given, there is no explanation on how the mitigation measures reduce the severity or the likelihood. An understanding of how a mitigation measure is controlling or reducing the risk is necessary to correctly implement that measure.

Considering the example with the "[f]ire in exhibition area" hazard, the mitigation measure is given as "Provision of First Aid Fire Fighting facilities" and the severity is reduced from 3 to 2. It might be deduced that the fire-fighting facilities are located close enough to lead to a quick response in the event of a fire, that there are sufficient people who are adequately trained in the use of the fire-fighting facilities, and that the area can be quickly evacuated. If this is the case, then it is reasonable to assume that there will be a reduction in the severity classification. If a person follows this example as given in CAP 403, however, and does not include all the additional information on what the mitigation measure actually means, then there may not be a high level of confidence in the reduction factor and the final risk rating.

The examples given for the mitigation in the table at paragraph A9 (reproduced in Table 4) appear to follow the guidance given elsewhere in CAP 403 i.e. the mitigation measures listed are merely the standard good practice. It would be expected that the general guidance given in CAP 403 would be followed as a minimum, and the initial risk has been assessed assuming that these measures have been implemented. Additional mitigation measures need to be considered in order to reduce the risk still further. The risk assessment guidance does not make this clear, and the examples could lead an assessor to assume that the measures given elsewhere in CAP 403 are sufficient to further reduce the risk. This should not be the case.

There is no explicit reference made to recording additional mitigation measures that may not be considered practicable, perhaps in terms of cost or implementation. If the examples given in Appendix A of CAP 403 are used as a template, then there may be insufficient evidence that all reasonable measures have been taken to reduce the risk.

The guidance makes it clear that the risk assessment should be recorded and uses the phrase “risk assessment process”. It could be deduced that this includes items such as the hazard identification process and statements concerning additional mitigation measures that are not practicable, but these are not explicitly stated. It would be quite possible for these items to not be included due to a lack of awareness on the part of the person carrying out the risk assessment.

No reference is made in Appendix A of CAP 403 of reviewing a risk assessment or from learning lessons from previous incidents. Undertaking a review prior to an event leads to greater assurance in the validity of the risk assessment. Reviewing the risk assessment after the event, and possibly during the event, enables it to be seen whether the implemented risk mitigation measures were successful at managing the risks and whether all the hazards were identified.

Many of the important points for undertaking risk assessments are covered in the guidance given in CAP 403. There are some aspects where some additional information could fill some potential gaps. Some of the examples given in the guidance do not provide enough detail of the full processes required. It is possible that a risk assessment based solely on this guidance would not ensure that risks were being managed ALARP.

2.7 GUIDANCE IN RELATION TO HEALTH AND SAFETY LEGISLATION

Appendix A of CAP 403, which contains the guidance on risk assessment, has been compared to the HSE guidance “Reducing Risks, Protecting People” (R2P2) [2], together with other published guidance [3, 4] and health and safety legislation (“Management of health and safety at work regulations 1999”) [5].

R2P2 outlines the principles that HSE uses to assess and control risks and may be regarded as guidance on how HSE would expect others to consider control of health and safety risks. Gadd *et al* [3] builds on the work of R2P2 and highlights some of the common failings seen with risk assessments i.e. the “pitfalls” of risk assessment. The HSE guidance, “Managing for health and safety” [4] is primarily aimed at providing guidance to commercial businesses, but the concepts used are more widely applicable and can be compared, in general, to the guidance provided in CAP 403.

The “Management of health and safety at work regulations 1999” [5] sets out the legal requirements with regard to managing health and safety in the workplace. It specifies the need for employers to have a risk assessment that is a “suitable and sufficient assessment” of the risks to the health and safety of employees and to the health and safety of persons not in their employ but who are exposed to risk through the employer’s undertakings e.g. spectators or surrounding populations.

2.7.1 Hazard identification

Paragraph 87 of R2P2 discusses the issue of ignorance in relation to the identification of hazards. In order to counteract this, a “wide engagement of different disciplines and communities of interest in the characterisation of the issue” should be undertaken. It also states that a further measure is to be as open as possible to enable alternative views to be considered at an early stage.

Gadd *et al* discusses failure to identify all hazards as one of the common mistakes made in risk assessments. The “Managing for health and safety” guidance [4] discusses the reasons for doing risk assessment. In particular it states that the outcome of the risk profiling will be that the right risks have been identified and that it will inform decisions about what control measures are needed.

All of the guidance states that a lack of awareness of the key hazards or risks is an indication of a lack of competence in the management of health and safety.

The guidance given in CAP 403 states in paragraph A1 that “it is necessary to identify these hazards and to minimise them”. The table in paragraph A4, which lists the five steps to risk assessment, states that identifying the hazards is step 1 in the process. It might be possible to improve the guidance in CAP 403 by providing more information on the importance of hazard identification, and also some indication as to how the hazards can be identified. As part of this additional information, some guidance can be provided on the people that should be involved, methods of recording the outcomes and also on keeping the effort required proportionate to the risks involved i.e. small events will require less effort and the involvement of fewer people than a large event.

2.7.2 Risk mitigation

Paragraphs 99 and 100 in R2P2 are concerned with identifying options to consider how to manage the risks. In particular, the use of experience is given as one way of identifying options. It also states that possible good practice should be examined as a way of addressing the hazards identified. Good practice needs to be evaluated as to whether it is relevant and sufficient for the hazards posed.

If specific good practice is not available then good practice that applies in comparable circumstances should be considered, if it is directly transferable to the hazard in question or can be suitably modified.

Section 4.15 of Gadd *et al* lists a lack of consideration of further measures that could be taken as one of the errors often made in risk assessments. It states that it is necessary to explicitly identify possible risk reduction options and assess whether they are reasonably practicable. In addition, “all options, or combination of options that are reasonably practicable must be implemented”. It goes on to say that each option should be measured against the present situation.

R2P2 states that it needs to be determined if there are any constraints attached to using a particular option e.g. is it technically feasible, are there any legal constraints etc. Also, any adverse consequences for using a particular option need to be considered e.g. a measure may reduce the risk from one hazard, but increase the risk from another hazard.

Section 4.18 of Gadd *et al* also states that it is necessary to examine the effectiveness of the risk control measure, and to consider whether any unexpected risks have been inadvertently created. The “Managing for health and safety” guidance [4] states that health and safety controls that do not seem practical are an example of poor worker consultation.

CAP 403 should outline “good practice” for airshow risk management as it represents the guidance offered by the industry body. Some modifications are required to the document to ensure that it is enabling the successful risk management of airshows. The main chapters provide information on various measures that need to be undertaken in order to protect the safety of both the spectators and the people working at the event. These measures would be expected to be carried out as a minimum. It would then be expected that the risk assessor would carry out an evaluation to determine whether these measures are sufficient for the hazards posed and then identify additional measures to reduce the risk further.

The specific risk assessment guidance given in Appendix A of CAP 403 provides examples of mitigation measures for three example hazards, although these appear to be taken from elsewhere in the guidance and hence represent "good practice". It does not discuss methods of identifying mitigation measures, or of how they can be assessed to determine whether or not they are suitable and sufficient, or whether they inadvertently introduce new risks. Providing additional information on these areas would improve the guidance.

It could be of benefit to explicitly state that there is an expectation that the measures contained within the main body of the CAP 403 guidance document are implemented as standard and the initial risk assessment will be based on that assumption. To reduce the risk, additional measures would need to be considered.

Paragraph 100 in R2P2 continues by stating that the "precautionary approach" should be used. In particular, as the degree of uncertainty increases, there is an increasing requirement for more stringent measures to mitigate the risks. R2P2 also refers to the relative costs and benefits of introducing a risk reduction measure. This can be used to determine whether or not a measure is proportionate to the level of risk involved.

The guidance in CAP 403 does make it clear, in paragraphs A12 and A13, that "mitigation action should be taken whenever possible to reduce risk ratings even when the risk is low" and that mitigation measures should be sought to reduce high risk ratings to an acceptable level. The guidance could be improved by making it clear that a greater amount of effort is expected to reduce the risks as the risk increases. Providing some examples of when a mitigation measure is identified that could be considered disproportionate, together with some examples of reasonable measures, may be of benefit and make the process clearer to potential risk assessors.

R2P2 has a section on evaluating the effectiveness of any action taken (paragraphs 115 to 117), and this is also covered in Section 4.18 of Gadd *et al*. In particular, R2P2 states that procedures should be in place to review the decisions made after a suitable interval. These should establish whether the actions taken were effective in controlling the risk, and whether any decisions needed to be modified as a result of new knowledge. An assessment should be made as to whether the information gathered to identify the hazards and mitigate the risks was appropriate, and whether improved knowledge and data can help make better decisions. An assessment should be made as to what lessons could be learned from the process.

It is further stated that having a system for monitoring and evaluating progress provides a "good opportunity to assess whether such 'established standards of good practice' are out of date. New developments such as better knowledge of the risk involved and advances in technology may indicate that a higher standard would be more appropriate to control the risk". The "Managing for health and safety" guidance [4] further asks the question of whether lessons have been learned from occasions where things went wrong and how the health and safety performance is reviewed. There is a whole section concerning the investigation of accidents and incidents, another on reviewing performance and a further one on learning lessons.

CAP 403 does not discuss the importance of reviewing risk assessments regularly. It is appreciated that the guidance will often be used for single events, where a review is less relevant. The guidance does, however, also cover events that are held regularly. It could be constructive to include some statements regarding the importance of reviewing any existing risk assessments, both prior to the event and afterwards. This could cover lessons learnt from risks that were well controlled, as well as from those that were less well managed. The importance of recording this information could be emphasised, as lessons learnt from individual events can ultimately be used to feed back into the guidance.

Within the guidance given on risk assessment, it may be beneficial to reiterate that, although these processes would be expected to be carried out for all events, the level of effort required should remain proportionate to the risks being assessed i.e. a small event with low risks will require significantly less effort than a large event with high risks. The aim is to encourage people to produce a risk assessment that is suitable and sufficient for the risks being managed and not to appear to be unduly onerous and burdensome.

2.7.3 Tolerability of risk

R2P2 introduces the “TOR framework” in paragraph 122. TOR refers to the Tolerability of Risk and aids in the categorisation of a particular risk. HSE represents this concept by an inverted triangle with the risk increasing as you move up the triangle (see Figure 1). If the risk is low, then it will fall into the “Broadly acceptable” region. As the risk increases, it moves into the “Tolerable” region and high risks may end up in the “Unacceptable” region.

Risks in the “Tolerable” region are described in Gadd *et al* [3] as “typical of those that people are prepared to tolerate in order to secure certain benefits”.

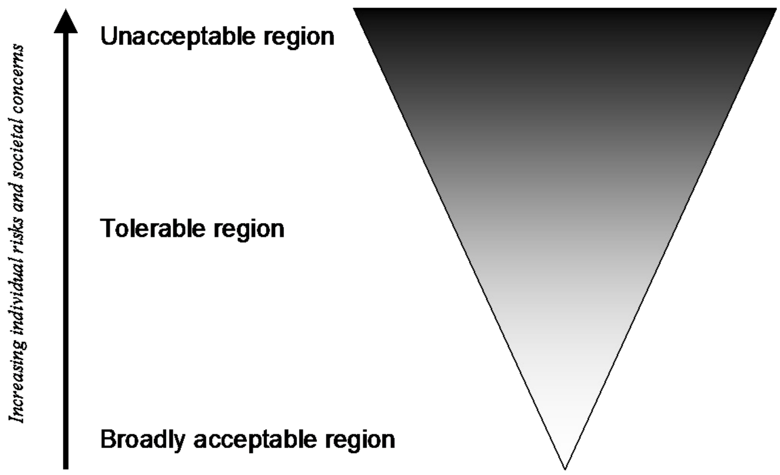

Figure 1 HSE Framework for the tolerability of risk [2]

In the description of the TOR framework, it is stated that any activity or practice that leads to a risk that falls into the “Unacceptable” region “would, as a matter of principle, be ruled out unless the activity or practice can be modified to reduce the degree of risk so that it falls in one of the regions below, or there are exceptional reasons for the activity or practice to be retained”.

R2P2 makes it clear that, even if a risk falls into the “Broadly acceptable” region, reasonably practicable measures to reduce the risks should be considered.

Within the “Tolerable” region in the TOR framework, it is expected that residual risks “are not unduly high and kept as low as reasonably practicable (the ALARP principle)”. It is also expected that the risks are reviewed periodically to ensure that they still meet the ALARP criteria e.g. by considering any new techniques or information that have become available. An assessment is needed to determine whether the risks have been reduced ALARP. The starting point of such an assessment should be the present situation in the duty holder's undertaking or, if this is not possible, an option which is known to be reasonably practicable (e.g. one which represents standard good practice). Any additional mitigation measures are considered against this starting point (i.e. existing situation or standard good practice) to determine whether or not they are reasonably practicable to implement to reduce the risk level (paragraph 5 in Appendix C of R2P2).

Gadd *et al* [3] is more succinct and states that "[r]educing risks ALARP means that if it is reasonably practicable to implement a risk reduction measure, it must be implemented." In addition, it states that "[d]uty holders should consider what more could be done to reduce a risk and why it is not being done i.e. whether or not it is reasonably practicable to implement any possible additional measures that are identified". A lack of consideration of ALARP or further measures that could be taken is recognised as a common mistake made in risk assessments and is discussed in Section 4.15 of Gadd *et al*.

The guidance given within CAP 403 clearly defines the different levels of risk in paragraph A11, although it uses the phrases low, medium and high risk. In paragraph A13, it states that "[h]igh risk ratings should generally be deemed unacceptable" and goes on to say that they should be reduced to medium or lower. This is in broad agreement with R2P2. In paragraph A12 it states that "[m]itigation action should be taken whenever possible to reduce risk ratings, even when the risk is low". This sentence is, in effect, stating that the risks must be reduced ALARP, although it does not use this phrasing.

Although the guidance appears to be following the ALARP principle, it could be beneficial to explain how to assess the effectiveness of any mitigation measures. CAP 403 uses the phrase "whenever possible" in regard to taking mitigation action. It might be of use to elaborate on what this phrase means in practice, with some examples given.

2.7.4 Risk management

In R2P2, paragraph 141, it is stated that HSE start with the expectation that the controls in place "should, as a minimum, implement authoritative good practice precautions (or achieve similar standards of prevention/protection), irrespective of specific risk estimates". Paragraph 142 goes on to state that authoritative sources of relevant good practice include "guidance agreed by a body representing an industrial or occupational sector". In this instance, the guidance provided by the Civil Aviation Authority (CAA) in CAP 403 should be implemented as a minimum.

R2P2 continues by stating that an assessment should be made as to whether adoption of the good practice is an adequate response to the hazards. As has already been stated in Section 2.7.2, CAP 403 provides a range of guidance for running air displays or special events. It may be beneficial to state within the risk assessment guidance that it would be expected that these measures will be carried out as a minimum and that an assessment will need to be made to determine whether or not they are sufficient for controlling the risks, or whether further measures are required.

In Section 4.19 of Gadd *et al* [3] the issue of not doing anything with the results of the risk assessment is discussed. It states that it is "essential that action is taken as a result of the findings of the risk assessment" and that it should not be considered a "paper exercise". At the end of the section it says "The assessment will almost inevitably result in recommendations for improvements and further actions to control and reduce risk …".

The second paragraph of Section 2 in Gadd *et al* [3] states "[t]he findings from a risk assessment can be used to inform decisions as to whether any existing precautions or control measures are adequate, or whether additional prevention or control measures are needed. Risk assessment can also be used to carry out a systematic comparison of different risk control/reduction options so that the optimal decision can be made".

CAP 403 mentions risk assessment in relation to the production of a safety plan. It could be beneficial to elaborate on this and include some of the information in Gadd *et al*, emphasising that the process is likely to lead to recommendations and identification of additional control measures. It might be worth including a comment in CAP 403 to stress the importance of recording the identification, assessment and implementation of additional control measures.

2.8 CAP 760 HAZARD AND RISK ASSESSMENT GUIDANCE

A comparison has been made with the CAP 760 [6] guidance produced by the CAA, which provides guidance on hazard identification, risk assessment and the production of safety cases. Although the guidance is primarily considering risk assessment and safety cases for system lifecycles, the principles used are generally applicable.

Areas of CAP 760 that are of direct relevance to the risk assessment guidance in CAP 403 [1] are highlighted. In some cases, it may be beneficial to include risk assessment information in CAP 403 similar to that given in CAP 760. Alternatively, the relevant sections of CAP 760 could be referenced in CAP 403 as an additional source of information that can be used by an assessor.

CAP 760 contains a glossary of all the terms used within the document, including specific risk assessment terms such as ALARP. CAP 403 does contain a glossary but it is not prominent and does not include risk assessment terms. It could be beneficial to move the glossary to a separate section in CAP 403 and include additional terms in a similar manner to the glossary in CAP 760.

Chapter 2 of CAP 760 introduces what it calls the "Seven-Step Process". This is similar to the five steps to risk assessment process given in CAP 403. Step 1 of the CAP 760 process provides a system description and Step 7 outlines documenting the process in a safety case. CAP 403 mentions the requirement to record the risk assessment in paragraph A14. Recording the risk assessment is not included explicitly in the five steps as quoted in CAP 403.

The seven steps in CAP 760 are given as:

- Step 1: System description;
- Step 2: Hazard and consequence identification;
- Step 3: Estimation of the severity of the consequences of the hazard occurring;
- Step 4: Estimation/assessment of the likelihood of the hazard consequences occurring;
- Step 5: Evaluation of the risk;
- Step 6: Risk mitigation and safety requirements; and
- Step 7: Claims, arguments and evidence that the safety requirements have been met and documenting them in a safety case.

A flow chart is provided to illustrate the process, which makes it clear that developing a risk assessment is often an iterative process. The flow diagram is reproduced in Figure 2.

Appendix K (Cont)

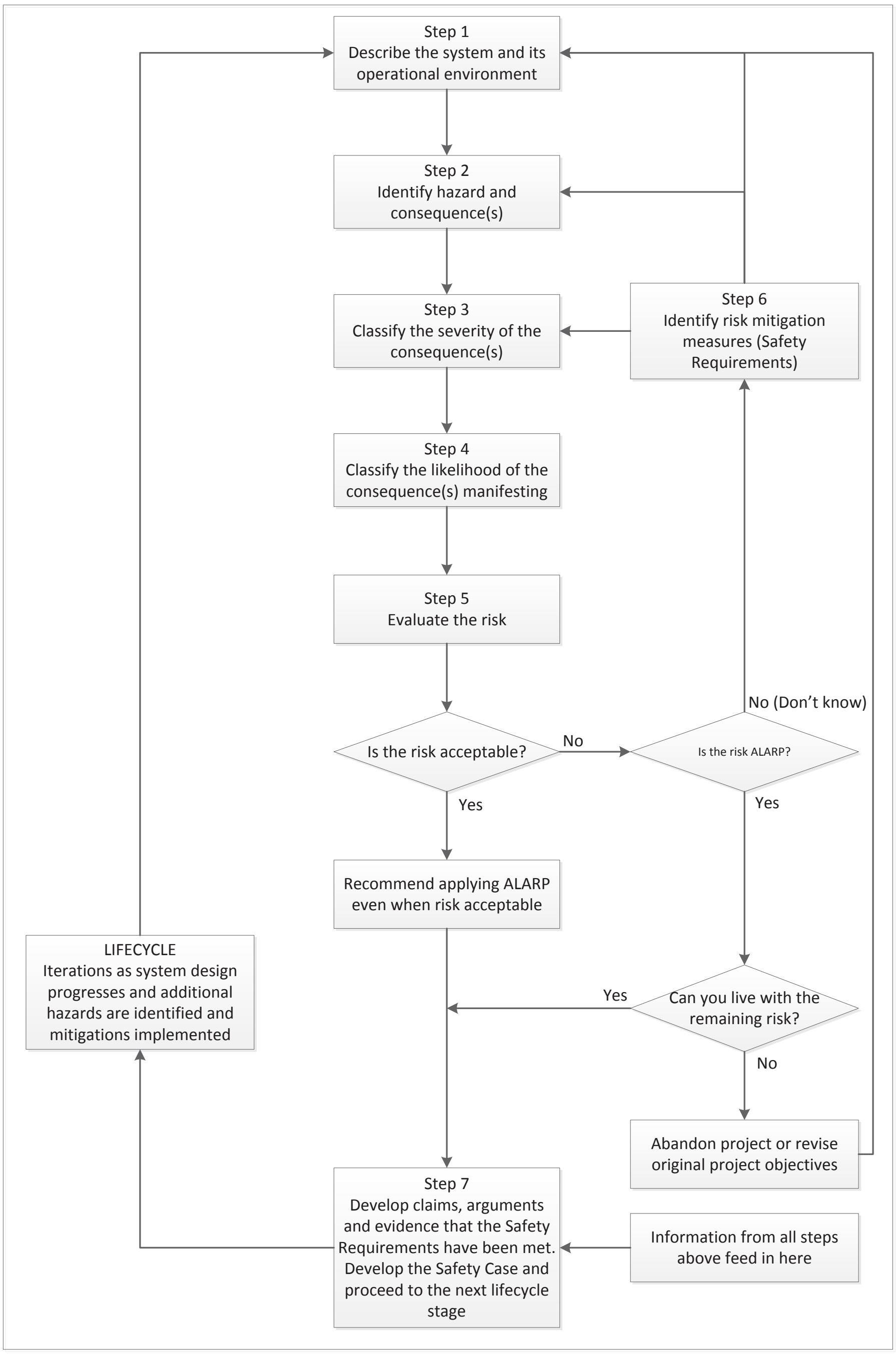

Figure 2 The Seven-Step Approach from CAP 760 [6]

Appendices

Chapter 3 of CAP 760 describes each of the seven steps in more detail.

For Step 2, the hazard and consequence identification, four key activities are described. These are:

- Create a hazard log;
- Identify the hazards;
- Identify the consequences of each hazard; and
- Update the hazard log.

A hazard log is described as a method used to document hazards. CAP 760 states that the log consists of forms that allow details of the hazard to be recorded, the risks associated with it and any mitigation measures. An example of the form is given in Appendix F of CAP 760.

It may be beneficial for CAP 403 to suggest that the information specified within the hazard log in CAP 760 is recorded in the risk assessments generated using CAP 403. A suggested format could be provided, if desired, noting that alternative methods can be used.

CAP 760 states that "[t]he hazard identification step should consider all the possible sources of system failure". It goes on to provide some possible examples of the types of systems that could fail. An equivalent sentence applicable to air displays could be used in CAP 403. Examples could also be given in CAP 403 for such a case, provided that it is noted that these are not exhaustive and that some may not apply to the event under consideration.

Details are provided of different hazard identification methods, including the use of historical information, brainstorming and systematic methods such as a HAZOP (HAZard and OPerability analysis). Some of these methods may not be suitable for the events covered under CAP 403 but a brief description of suggested methods that are suitable (e.g. brainstorming) could be of benefit to potential risk assessors.

CAP 760 emphasises the need to record the results of the hazard identification in the hazard log, and provides information on what information should be recorded. This is given in Step 3 of the seven step process and includes the severity of each consequence (noting that there may be more than one consequence for each hazard) and the rationale behind the severity classification chosen. Guidance is given on how to assess the severity. Similar information could be provided in CAP 403, perhaps with one or two examples, noting that the severity classifications are already given in Appendix A of CAP 403.

Step 4 considers the estimation and assessment of the likelihood of the consequences occurring, the results of which must be recorded in the hazard log. Similar methods to those used in Steps 2 and 3 are advocated and the terms used (extremely improbable, extremely remote etc.) are equivalent to the terms used in CAP 403. CAP 760, however, also includes a numerical range to provide some quantification for the qualitative terms (e.g. $< 10^{-9}$ per hour, 10^{-7} to 10^{-9} per hour etc.) as well as a qualitative definition (e.g. should virtually never occur, very unlikely to occur etc.).

CAP 403 may benefit from the addition of a paragraph providing guidance on how to determine likelihoods. The use of a more quantitative definition for the terms used, or a more detailed qualitative description, could help with consistency between risk assessments produced by different assessors. An example of a quantitative definition could be given, although it would need to be recognised that it might not be applicable for all sizes and types of event. A more detailed qualitative description would also help to remove ambiguity, particularly if a quantitative definition is not suitable. Over time, the definitions used within individual risk assessments could be collated to see if any consistency has been developed, and these could be incorporated into future guidance.

CAP 760 provides a colour coded risk matrix and describes the three different regions within it, which it names as acceptable, review and unacceptable. As in the case of CAP 403, it notes that even acceptable risks (or low risks in the CAP 403 terminology) should be assessed to see if they can be reduced still further. CAP 760 provides more detail about what each of the terms means in practice. Including this detail in CAP 403 may be of benefit as it provides a clearer understanding of the terms and can also provide an indication of the level of effort required to reduce the risks.

There is a discussion in CAP 760 around different hazards producing the same consequence. The guidance makes it clear that it is the risk of the consequence that is being assessed, not the hazard itself e.g. if there are several hazards with the same consequence, the likelihood of each hazard may be low, but the combined likelihood of all the hazards leading to the consequence being assessed is considerably higher. In such a case, individual hazards should not be treated independently as it could lead to the risk being assessed as lower than the risk that would be associated with the actual consequence. Guidance is given in CAP 760 on how to accumulate the likelihoods, and how to mitigate the associated risk.

This is an area that is currently not considered in CAP 403 and a paragraph covering this topic could be included as this is a point that could be easily missed by an assessor. If this was added to CAP 403 then also including a suitable example would aid clarity.

CAP 760 states that the assessment must be clearly recorded, particularly where the risk has been assessed as being in the review region of the matrix but the conclusion is that the risk is ALARP. Justification for the decision needs to be clearly stated.

This last point has been discussed elsewhere in this document (e.g. Section 2.3.1). It may be of value to potential risk assessors if CAP 403 provided a clearer link between risk mitigation and reducing risks ALARP. Including explanations for decisions made in the risk assessment would lead to more confidence in the output of any risk assessment produced using the guidance.

For Step 6, CAP 760 provides guidance on risk mitigation and safety requirements. It reemphasises the recommendation that all risks are reduced, if possible, including those that fall into the acceptable region of the matrix. It provides examples of risk mitigation strategies and states that the mitigation may either reduce the likelihood or the severity of the consequence, or possibly both. The potential issue of a mitigation measure introducing new hazards is also highlighted in the guidance.

CAP 403 currently provides limited information to a risk assessor on mitigation measures and how to assess the impact of mitigation on the level of risk (likelihood, severity, or both). It may be beneficial to include a paragraph giving a broad outline containing similar information to that contained within CAP 760 on this area. Examples of the types of mitigation measures that may be worth considering could also aid clarity, although it would need to be made clear that these measures may not be exhaustive and/or appropriate in all situations and that other measures may be more suitable to consider and implement.

Step 7 in the CAP 760 process relates to the generation of safety cases, but does include guidance to ensure that the results of the previous steps are documented in a “logical and complete” manner.

CAP 403 currently states that the details of the risk assessment process should be recorded. It may be of use to assessors if CAP 403 provided more guidance as to what information should be recorded as part of the risk assessment process.

If it is decided that producing a hazard log would be a beneficial addition to the guidance, examples of how to complete one could be given and this would form a significant part of any final risk assessment. The log would include the hazard identification process, the identification of the consequences, the assessment of the likelihood and severity of each consequence, the initial risk rating assessment, the identification and assessment of mitigation measures, and the final risk rating including all justifications for why the risk cannot be reduced further. In other words, the guidance currently given in CAP 760 could be adapted for use within CAP 403.

2.9 SUMMARY OF OBSERVATIONS

2.9.1 Risk assessment good practice in the guidance

The previous sections have provided a number of comments on the risk assessment guidance given in CAP 403. In summary, the areas of good practice are:

- Recognising the importance of undertaking a risk assessment;
- Recognising that a risk assessment need not be complicated;
- Listing a simple to follow 5 steps to risk assessment (noting that these do not completely correspond to the risk assessment 5 step process given by HSE);
- Stating that the risk assessment must be undertaken by someone who is aware of the risks associated with the activity;
- Providing the basis of a risk matrix that recognises that it is injury to people that is of importance when assessing the risks;
- Providing an example of how to use the matrix, including attempting to show how mitigation measures may reduce the risk (it is recognised that there are some aspects that are missing from the example table given, but the principle is good);
- Indicating what the risk ratings mean in terms of low, medium or high risk;
- Stating that mitigation measures should be considered even when the risk is low;
- Recognising that high risk activities are generally unacceptable and that the risks must be reduced to medium or low. In particular, not stating that the risks must be reduced to low risk, but recognising that medium risk is acceptable. In this case, further statements should be made to state that medium risk is acceptable provided they are ALARP, but the principle of not enforcing all risks to be low is good; and
- Stating that the risk assessment process should be recorded and retained.

2.9.2 Changes to the guidance

The review has identified a number of areas where changes could be made to the guidance that would be of benefit to a risk assessor.

There are several key points that have been raised within the review of CAP 403 where changes should be made to the guidance to ensure that any risk assessment produced using the guidance will effectively manage the risks from an airshow.

- The qualifications and experience required for the people undertaking the risk assessment should be clearly identified in the guidance. This will ensure that people with sufficient knowledge to identify the hazards and the mitigation measures, and to assess the associated risks, will undertake the risk assessment;
- The information in the guidance on hazard identification should be amended. The guidance in CAP 403 could emphasise the need to identify all of the hazards, and provide some information on how to identify hazards.

  CAP 403 could highlight that the hazard identification process should be recorded, including keeping a record of hazards that were identified as part of the process but subsequently dismissed as not being applicable for the event being assessed.

  CAP 403 could include more information to ensure that assessors think about who is affected by the hazard and where they might be located in relation to the hazard. Including examples and/or a possible format to use for recording purposes could provide additional support to airshow organisers and assessors;
- The existing guidance is potentially misleading around the area of risk mitigation. More advice is required to guide organisers and assessors to consider where, how and why the mitigation measures suggested do reduce and control the risks. Failing to provide this information could lead to uncertainty as to whether the risks have been reduced As Low As Reasonably Practicable (ALARP) and, consequently, whether the risks would then be sufficiently controlled;
- The guidance implies, through the examples given, that the requirements for running an airshow listed in the main chapters of CAP 403 can be used to mitigate the risks from the identified hazards. CAP 403 should be taken as the minimum requirement and the risks assessed initially assuming that the guidance has been followed. Identified mitigation measures to lower the risk should go beyond those contained within the guidance.

  Providing additional information in CAP 403 on how to identify mitigation measures, and assess that the measures are appropriate and achievable, would be of benefit. Revised examples removing the CAP 403 mitigation measures and including some simple alternative measures could help deliver this message more clearly.

  CAP 403 could ask that the process for identifying and assessing mitigation be recorded. This would allow the inclusion of mitigation measures that were considered and then legitimately dismissed as being impracticable. Including examples and/or a possible format to use for recording purposes could provide additional support to airshow organisers and assessors; and
- The tolerability of risk criteria currently used (i.e. the definitions of high, medium and low risk) should be reviewed. The current criteria has some significant consequences occurring in timeframes that cannot be perceived as cautious. Consideration should be given to modifying the definitions used e.g. this could be as simple as specifying that risks with a rating of 15 or higher should be classed as high.

Areas of CAP 403 where additional modifications could be made to provide further assistance to those carrying out risk assessments have also been identified.

- It would be beneficial to move the risk assessment guidance in CAP 403 to a separate chapter, rather than a paragraph in Chapter 4 with the detail given in the Appendix. Placing it in the main part of the document will give it more emphasis, thereby reinforcing its importance as part of the safety management at air display events.

  It would also be useful to include links or references to guidance given by HSE and/or other CAA guidance (e.g. CAP 760). This would provide assessors with additional support and information as required;
- The risk matrix should be explicitly included within the guidance to make it easier for an assessor to determine where the risks from an activity lie;
- Guidance should be provided on the need to regularly review the risk assessment, particularly for airshows that will occur more than once (e.g. annually). This provides assurance that any new risks introduced at a subsequent airshow are considered and managed, and also that lessons have been learned from previous airshows; and
- The guidance could clearly state that the risks from the airshow do not need to be reduced to low risk and can remain as medium risk, provided that it is demonstrated that the risks are effectively managed. This ensures that people involved in the airshow are aware of the more significant risk activities.

There are other points where suggestions have been made that could potentially improve the risk assessment guidance in CAP 403. Consideration should be given to these suggestions to determine whether it would be of benefit to make the associated changes to the guidance.

- Including an alphabetic glossary of all terms used and putting the glossary in its own section;
- Providing more detail on the qualifications and experience of those identifying the hazards;
- Adding "reviewing the risk assessment" as part of the five steps to risk assessment in the guidance;
- Suggesting the use of maps to aid with assigning a severity classification;
- Providing additional wording for the likelihood classification and/or some guidance to suggest that the risk assessor must define and record the likelihood classifications that are applicable to the event being considered;
- Stating that risk assessments for the air display and for the ground based activities of the airshow should be carried out separately, especially at large events and with a further recommendation that this is followed for all sizes of event;
- Recognising the importance of learning from previous incidents and recording the lessons learnt;
- Making it clear that the risk assessment should be available for all people associated with the event and that they should particularly familiarise themselves with the parts pertinent to their role;
- Providing links to other risk assessment guidance, including CAP 760 [6]; and
- One other general area of improvement in the guidance is clarifying exactly who is responsible for undertaking each task.

2.10 IDENTIFICATION OF GUIDANCE FOR OTHER EVENTS

An internet search was undertaken to ascertain what guidance is available for organisers of other public events. These include Formula 1, car rallies, speedway, motocross, trials and track racing, the Isle of Man TT, events covered by British Cycling, horseracing and general events that occur on the highways.

The FIA (Federation Internationale de L'Automobile) cover Formula 1 and rallying events. The guidance that could be found on the internet mentions the need for a safety plan and for keeping the public away from the cars, but no specific risk assessment guidance was found. Most of the information related to safety measures are for those involved in the race.

In the case of speedway, it is made clear who is responsible for carrying out the risk assessment but no guidance could be found. Each individual track appears to have its own risk assessment.

The ACU (Auto Cycle Union) provide a risk assessment form for motocross, trials and track racing. To obtain copies of the guidance, membership of the ACU is required.

The Isle of Man government provides general guidance for events such as the TT. This includes a generic risk assessment form.

Guidance is available from British Cycling for club events, which appears to be reasonably comprehensive. Guidance for both competitive and non-competitive events is only available to members of British Cycling, and it only appears to be available for certain types of event. Forms are provided for completion.

An example of a safety handbook is provided for horseracing events by the RCA (Racecourse Association Limited). Mention is made of risk assessment but no guidance was found.

Events on the highways are covered by the local highways authority, which is either the county council or the city/metropolitan council. Guidance is provided in a Home Office document on how to carry out a risk assessment and it is made clear that it is the responsibility of the event organiser to do the risk assessment.

None of the guidance identified was considered suitable for use as a benchmarking exercise with CAP 403 due to a general lack of detail in the advice given.

3 CONCLUSIONS

A review has been conducted of the risk assessment guidance given by the Civil Aviation Authority (CAA) in CAP 403 [1] for flying displays and special events. The review has been carried out by the Health and Safety Laboratory (HSL) at the request of the Air Accident Investigations Branch (AAIB). This review has included a comparison of the risk assessment guidance within CAP 403 with Health and Safety Executive (HSE) and other risk assessment guidance [2, 3, 4], health and safety legislation [5] and with other CAA risk assessment guidance [6]. The review has aimed to address seven areas, identified as being of importance by the AAIB and HSL.

A number of observations have been made of good practice in hazard and risk assessment in CAP 403. There are some areas of the guidance, however, where additional information could be of benefit to those using it and would potentially lead to greater confidence that a risk assessment created using the guidance will be suitable and sufficient for managing the risks.

This study has identified areas of the guidance where changes are required to give airshow flying display organisers the information needed to undertake meaningful risk assessments, or in some cases, to avoid misleading organisers on what needs to be done. Ultimately, these improvements should ensure that the risk assessments help airshow organisers to target and control the risks from flying displays.

- Identifying the right people to assess the risks

  CAP 403 should clearly list the qualifications and experience required of the people who should be involved in assessing the risks. This will ensure that people with sufficient knowledge to identify the hazards and the mitigation measures, and to assess the associated risks, will undertake the risk assessment;

- Improving guidance on hazard identification

  CAP 403 should include some additional information to stress the importance of the hazard identification process to the quality of the overall risk assessment. This could include advice on defining what is meant by a “hazard”, and recommending that more information is provided in an assessment explaining the thoughts of the assessor behind the hazards identified.

  The CAP 403 guidance could also recommend that a record be kept of the hazard identification process. This allows an understanding of the expertise used by the personnel involved in the process and would allow an understanding of the reasons why some hazards have not been considered further in an assessment;

- Issues with the guidance on mitigation measures

  An area where the existing guidance in CAP 403 is potentially misleading is concerning the area of risk mitigation. This is a significant area that needs to be improved as failing to properly assess the mitigation measures could lead to inappropriate or unachievable measures being put in place that do not control or reduce the risks.

  The guidance uses examples where CAP 403 requirements to allow an airshow to go ahead are used as measures to mitigate the risks from the identified hazards. The guidance in CAP 403 should be taken as the minimum requirement and the risks assessed initially assuming that the guidance has been followed. Identified mitigation measures to lower the risk should go beyond those contained within the guidance.

It should be explicitly stated that an explanation of how the identified mitigation measures lower the severity or likelihood classification in the risk assessment calculation should be recorded. Additional information on how to identify mitigation measures and assess the impact of the measures, together with revised examples should be included in CAP 403. CAP 403 should encourage assessors to demonstrate that the risks have been reduced As Low As Reasonably Practicable (ALARP) for the air displays; and

- Risk criteria review

  It is recommended that the tolerability of risk criteria currently provided in CAP 403 (i.e. the definitions of high, medium and low risk) are reviewed to assess whether these need to be modified. Risks are currently classified as high if the risk level is calculated to be above 15. Using this scoring system means that there are some high consequence events that are deemed "tolerable" for relatively frequent likelihoods. A review would clarify whether the criteria are acceptable or whether a change would be appropriate.

This study has also identified areas within CAP 403 where additional information or restructuring could help airshow organisers and risk assessors when assessing the risks.

- Location of the risk assessment guidance in the document

  Moving the risk assessment section out of the appendices of CAP 403 and into the main body of the document would raise awareness of the importance of generating a risk assessment. Detailed examples and additional information could be retained in appendices;

- Including the risk matrix as a visual aid

  The risk matrix should be explicitly included within the guidance to make it easier for an assessor to determine where the risks from an activity lie;

- Highlighting the need for regular reviews of the risks assessed

  Guidance should be provided on the need to regularly review the risk assessment, particularly for airshows that will occur more than once (e.g. annually). This provides assurance that any new risks introduced at a subsequent airshow are considered and managed, and also that lessons have been learned from previous airshows; and

- Guidance on reducing and controlling risks

  The guidance could clearly state that the risks from the airshow do not need to be reduced to a low risk level and can remain as medium risk, provided that it is demonstrated that the risks are effectively managed. This is to ensure that more significant risks are treated with the appropriate level of caution.

Some additional modifications to CAP 403 have been identified that would add further value to the document and potentially make it easier for airshow organisers and risk assessors to undertake assessments to control the risks.

- Clearly distinguishing the air display risks from other risks

  Specifying that the air display risk assessment and the ground based aspects should be separated in some way to distinguish between these different aspects of the airshow. This would ensure that those who need to be aware of the air display risks, and the measures to mitigate them, do not inadvertently ignore some of the risks through having the details of these risks and mitigation included with the risks from ground based activities;

- Making the glossary more accessible

  Moving the glossary to a separate section and including all risk assessment terms would aid the clarity of the guidance given to the people undertaking the risk assessment. Ensuring that the glossary is in alphabetical order would be of further benefit; and

- Clarifying risk assessment responsibilities

  Carrying out a risk assessment should be clearly listed as one of the requirements and responsibilities of the Event Organiser and the FDD. This will help emphasise the importance of the risk assessment, and who should be responsible for ensuring that a risk assessment is undertaken.

4 REFERENCES

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6. CAA (2010). *Guidance on the conduct of hazard identification, risk assessment and the production of safety cases.* CAP 760.

7. *Controlling the risks in the workplace.* http://www.hse.gov.uk/risk/controlling-risks.htm, accessed 23 March 2016.

Appendix K (Cont)

HEALTH & SAFETY LABORATORY

The Health and Safety Laboratory (HSL) has been developing health and safety solutions for over 100 years. Our long history means that we're well-placed to understand the changing health and safety landscape, and anticipate future issues.

We are part of the Health and Safety Executive (HSE) – this gives us a unique insight into the changing face of workplace health and safety.

HSL employs about 400 staff, who help make working environments and working lives safer, in the UK and around the world. From our base in Buxton, and with staff in six other locations across the UK, we focus on the development of practical solutions to health and safety problems.

Our scientists have a strong international reputation for world-class research, undertaken on behalf of HSE and other sponsors in government and industry.

ISO 9001 ISO 14001 OHSAS 18001

Health and Safety Laboratory
Harpur Hill
Buxton
Derbyshire
SK17 9JN
UK
www.hsl.gov.uk
T : +44 (0) 1298 218218
E : hslinfo@hsl.gsi.gov.uk

Appendices

Appendix L

Airworthiness Approval Note No: 26172 Issue 2

Civil Aviation Authority

AIRWORTHINESS APPROVAL NOTE NO: 26172 Issue 2

APPLICANT:	CAA Internal Purposes	
AIRCRAFT TYPE:	Hawker Hunter T7	
REGISTRATION NO:	G-BXFI (Ex: WV372)	CONSTRUCTOR'S NO:41H-670815
CERTIFICATE CATEGORY:	Permit to Fly	

To Approve Hawker Hunter T Mk 7 Registered G-BXFI for the Issue of a Permit to Fly

1. **Introduction**

Hawker Siddeley Aviation Limited manufactured the Hunter aircraft for the Ministry of Defence and the type designated the T Mk 7 was a two seat version. This aircraft was originally manufactured as a single seat aircraft and was delivered on 2 September 1955. The aircraft was then converted to a two seat version under contract number 6/Acft/15381/CB.9(c) and cleared against Hunter Mk 7 Y.1 conversion leaflet on 21 May 1959 at Sir Armstrong Whitworth Aircraft Limited, Baginton Aerodrome, Coventry. It was delivered on 1 June 1959 with 223 hours and 30 minutes accumulated.

The new formal owner is Fox-One Limited. The aircraft will be housed, maintained and operated from Jet Heritage Limited based at Bournemouth International Airport.

Issue 2 of this AAN has been raised to record that a starter engaged warning light has been fitted to this aircraft, see Section 4.1.1 below.

2. **Description**

The Hawker Hunter was designed as a single seat fighter with swept wings, variable incidence tailplane (electrically actuated follow-up trim) powered aileron and elevator controls and pressurized cabin. The T Mk 7 is a two seat side-by-side trainer/operational version intended for training and conversion operations and is powered by a Rolls-Royce Avon Mk.122 turbine engine.

APPLICANT
CERTIFICATION AND APPROVALS DEPARTMENT

AD166/2
300304

This aircraft was originally built as a single seat Mk.4 and then converted to a T Mk.7 the number given above is that of the fuselage. A detailed description of the aircraft may be obtained by reference to the publications listed in section 6 below.

The following Jet Heritage modifications have been installed:
i) JH 034 Engine Starter: which replaces the AvPin starter system
ii) JH 037 Gun ballast: which replaces the guns with ballast.
iii) New Avionics.

3. **Approval Basis**

The original basis of Service acceptance is AvP-970, the type record exists and the design authority now rests with the RAF and support is supplied, if requested, by British Aerospace, Farnborough. CAA approval is based on the satisfactory service history of the type (accepted by precedent) and investigation carried out in accordance with policies agreed by the ARB during the meeting of 23 April 1992 appropriate to the aircraft's classification in the *intermediate* category.

4. **Technical Investigation**

The aircraft incorporates hydraulic powered ailerons and elevators with automatic manual reversion in the event of hydraulic failure. This aircraft has fully powered hydraulic boosters which can be switched into manual and back to power and will engage satisfactorily.

The tailplane trim is electrically powered and a back-up actuator is provided in case of failure of the main system. The autostabilizer (mod 417) is not embodied on this aircraft (deleted by mod 1068). The aircraft has wing leading edge extensions and "Dog tooth" (mod 533) fitted to alleviate pitch up caused by tip stall at high Mach numbers. The electrically actuated "follow-up" tail (modifications 390 and 629) is embodied (electric trim is manually selected).

Armament originally consisted of one 30 mm Aden cannon in the lower forward fuselage, however the cannon has been removed and replaced with appropriate ballast during service use. The T Mk. 7 aircraft was capable of carrying a variety of underwing stores but of these only drop tanks are retained.

A complete service has been carried out and all defects rectified and recorded in the aircraft's Rectification book.

4.1. **Modification State.**

The applicant confirms that all modifications classified as B/2 or above (with the exception of armament related modifications) have been embodied on the aircraft.

All relevant UK STI's have been complied with and SI's satisfied.

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The applicants modifications are as follows:

4.1.1. Modification JH 034: Introduction of revised electrical start system for Avon engines.

This modification introduces an electric start system. The existing IPN system has been removed except for the tank. A Rotax electric starter motor is fitted in the nose of the engine (as originally developed between the company under the name of Brencham, in conjunction with Rolls-Royce, based on the latter's test bed system). No adaptor is required, as the Avon is designed to be capable of start in this manner. In order not to compromise the existing electrical system, the new system is kept completely separate from the existing aircraft electrical power and distribution system (EP & DS). This has been achieved by fitting 10, 12 volt sealed gel lead acid batteries in the gun pack after removal of the 30 mm cannon and ammunition. These batteries supply power to the solid state electronic sequencing unit and the power for the starter motor. Modern solid state switching is used.

The batteries are mounted in mild steel carriers which are rigidly attached to the structure. The battery weight of 183 lbs is less than the ammunition weight. Similar modifications have been applied to the applicant's (under the name of Brencham) previous aircraft G-BOOM (AAN 17422), G-HVIP (AAN 25239) and G-VETA (AAN 25853).

A starter engaged warning system has been installed, so that the pilot is made aware of overspend of the starter (and potential catastrophic failure induced by this). This warning system has been installed under minor modification DEA00001 approved by CAA under reference 9/203/MOD/99/30AV.

4.1.2. Modification JH 037-Ballast in lieu of Gun pack on Hunter aircraft.
The gun pack has been removed from the aircraft and replaced with a gun cradle with special cast lead blocks which are bolted to the gun cradle in order to maintain the C of G within limits.

4.2 <u>Fatigue State</u>

A Mk. 14 Fatigue meter has been fitted to the aircraft for its entire life (current meter is serial number 1249-M-62 and the operational life consumed has been accounted for in the accordance with AP4347G (now AP101B-1302-1) Section 2 Chapter 3.

The records indicate:

i) Centre fuselage FI is 28.236 at 5566.25 airframe hours.
ii) Port wing FI is 50.347
iii) Starboard wing FI is 29.437

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Records indicate that at 5566.25 airframe hours the FI is:

Item	Serial No:	FI	FI Limit	FI Remaining.
Fuselage	41H/670815	28.236	100	71.764
Port Wing	41H/670529	50.347	111	49.653
Stbd Wing	41H/R/S4/675687	29.437	111	70.563

i) The frame 25 tie bar is limited to 100 FI and no recovery scheme exists.
ii) The mainplane front spar lower boom is limited to 111 FI but the remainder of the wing is limited to 180 FI if this is replaced.
Additionally STI/Hunter/431 requires inspections at 6 FI intervals of shoulder fillets of wing spar lower lugs for those spars not conforming to D41170 Issue 2.

When the centre fuselage reaches 35 FI, the spigots at Frame 19 become subject to SI/Hunter/96 unless Mods 1327 and 1334 (which replace the fuselage mainplane locating spigots on the centre section and wings) are embodied. Modification 1032 (spigots and nuts of front fuselage transport joint) has been embodied.
The fatigue state of this aircraft is therefore considered satisfactory and is to be monitored using the system laid down in AP101B-1302 Section 2, Chapter 3. MoD Format F725 will be used for this purpose, so that fatigue state is recorded after each days flight.

4.3 Engine

Rolls-Royce Avon Mk 12201 engine, serial number 6020 is fitted. All filters have been cleaned and inspected and all applicable STI's and SI's carried out and recorded in the engine log book. 130:12 hours remain of its 450 hour time between overhauls. The engine has been inspected in accordance with the relevant RR/RAF maintenance manuals.

Engine cycle usage rate (including ground running for maintenance checks and in lieu of corrosion inhibiting) will be accounted for in accordance with Rolls Royce manuals viz 4.0 cycles equal 1 flight hour.

The triple breech cartridge starter system has been replaced by Jet Heritage's electric start modification. Fire warning and extinguisher systems are provided and are operational. The oil supply system limits negative g to 10 seconds operation only.

4.4 Ejector Seats

Martin-Baker type 4HA Mk 1 and 2 seats, Serial No: 19 and Serial No: 20 have been serviced in accordance with AP 109B-0131-12. The parachutes and survival packs have also been serviced in accordance with the relevant Air Publications. Ejection procedures and envelope are specified in the Aircrew Manual.

Cartridges for the Aircrew Assisted Escape System have a 6 (six) year overall/shelf life and 2 (two) year installed life. For the fire suppressant system the cartridges have a 5 (five) year installed life. New cartridges for both system have been purchased and installed. Jet Heritage has arrangements for the safe disposal of time expired cartridges.

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4.5 Drop Tanks

The aircraft has a capability of carrying 4 x 100 gallon, jettisonable fuel tanks (not gauged) on the pylons. Fuel transfer is by means of air pressure from outboard to inboard and then to the wing tanks. CAA Project Department Circular No: PDC 012 has been examined and complied with, with respect to the drop tanks.

The requirements have been met by the addition of a master arm switch, located within the cockpit above the two guarded jettison buttons. To activate the jettison buttons, the master arm switch must first be placed to "ON" and then the pilot selects the appropriate station that is to be jettisoned. The surrounding panel has been cross-hatched black/yellow, identifying the emergency nature of the controls. This system is described in an amendment to the Pilots Notes, reference JHL/AL/3.AP 4347G-P.N. The flight reference cards have also been changed to include this master arm switch in the normal cockpit checks. Jettison is only to be carried out in an emergency.

4.6 Weight and Balance

The aircraft has been weighed by Loadmasters and report 98JY098 dated 28 July 1998 refers. This confirms that the aircraft will remain within weight and C of G limitation with pilots of 120 lbs to 250 lbs at any fuel state (Pilots weight identified as 180 lbs).

4.7 Electrical System

Jet Heritage engine start modification includes a starter engaged warning light to comply with Airworthiness Notice 33. This modification does not affect the remainder of the aircraft electrical system and capacity of batteries employed for the start is not available to electrical services in the event of a double generator failure. Because there are two generators, either of which is capable of providing the entire load required and dolls-eye indicators (or warning lights) warn of failure of each, battery capacity has not been assessed against Airworthiness Notice 88. A battery master switch is provided.

During restoration of this aircraft, all the electrical cables were physically inspected and particular attention was paid to known hazardous areas. Any terminations considered suspect were cut-back and remade. The insulation was visually found to be in an acceptable condition.

4.8 Radio

Original military equipment has been replaced under minor modification HL/MOD/294. The radio fit is as follows:

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No	Function	Manufacture	Type
2	Comm Tx/Rx	Becker	AR4201
1	Transponder	Becker	ATC2000-3-R
1	Altitude Encoder	Kollsman	
1	Colour Skymap GPS	Skyforce	CM2000

4.9 Miscellaneous / Operational Aspects

The aircrew manual states that the negative 'g' fuel traps provide capacity for "approximately 10 seconds" of negative 'g' flight.

The brake parachute is not to be relied upon to enable planned landing at a field shorter than that which would be required without this parachute. The brake parachute may be deployed to save wear on the undercarriage, tyres and braking units.

The aircraft's main oxygen system and emergency system is fully operational and the Mk5D bottles and the emergency oxygen bottles fitted to the ejection seats (one to each seat) have been overhauled, which included hydro-static test, during the aircraft's restoration. The cabin pressurization, windscreen de-icing and anti 'g' system are operational.

This aircraft has fully powered hydraulic boosters and therefore can be switched into manual and back to power and will engage satisfactorily. A placard warning not to engage manual unnecessarily during flight is therefore not required.

5. Flight Test

The aircraft was flight tested on 11/09/98 by a pilot with current type rating and who has been accepted for the purpose by the CAA to schedule HO/FTR/8403; which is based on RAF schedule ref: AP 101B-1302-5M, modified and agreed by the CAA. Flight Department report FTR 10562 confirms that it is satisfactory for the issue of a Permit to Fly.

6. Manuals

Jet Heritage has a complete set of manuals AP 101B-1303; including Bay Servicing requirements for components and the following:

AP 101B-1302 & 3-15	Hunter Mk T7 Aircrew manual (amended to AL 9 December 1992)
AP 101B-1302-1	Hunter Mk T7 Aircraft Servicing Manual
AP 101B-1302-2	General Orders and Modifications
AP 101B-1302 -3 Pt 1	Parts catalogue
AP 101B-1302-6A	Repair manual
AP 102C-1512 to 1517-1	Avon 100 series General and Technical
AP 102C-1512 to 1517-1	Avon 100 series In-service Repairs
AP 109B-0131-15F	Ejection Seat Mk 4 General and Technical

The weight schedule referenced in 4.6 above, will be appended to the Aircrew manual, in order to ensure that the pilot has sufficient information to check weight and balance prior to flight.

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7. **Noise Certification**

A noise certificate is not required for this aircraft as it operates on a Permit to Fly.

8. **Limitations and Concessions**

Airframe and Engine limitations are given in AP 101B-1302 and 3-15; Aircrew Manual, except that those below are to be employed where they are different (* will be identified by a placard or otherwise marked on gauges):

*1. Acrobatics are permitted in accordance with the Pilots Notes, however flick manoeuvres and intentional stalling and spinning are prohibited..

2. Reliance is not to be placed upon the brake parachute when planning a landing. It is not to be streamed before touchdown and a speed limit for streaming is 160 knots.

*3. Load Factor limitations: +7.0/-3.75 g. Negative 'g' is limited to 10 seconds duration only.

4. C of G to be between 1.0 inches forward of datum and 14.5 inches aft of datum. Datum is marked by a spigot in the port main undercarriage bay.

5. Weights:

Maximum take-off	25000 lb (11340 Kg)
Normal landing	18500 lb (8392 Kg)
Emergency landing	23400 lb (10614 Kg)

*6. Airspeed Limitations (see AP 101B-1302 and 3-15) summary follows:

Max speed, power boosted controls on	620 knots
Max speed, manual controls below 15,000ft	0.75Mach (0.85M above 15,000ft)
Undercarriage operation/deployed	250 knots
Flaps 0 degrees to 38 degrees	300 knots (or 0.9M)
>38 degrees and fully down	250 knots

*7. Engine limitations (see AP 101B-1302 and 3-15) summary follows:

Rating	RPM	JPT (C)	Duration
Take-off	8100	690	10 mins
Intermediate	7950	655	30 mins
Max. Continuous	7700	625	- - -
Min. Approach	4500	-	- - -

*8. Day VMC only

*9. No smoking

10. Fatigue is to be accounted in accordance with section 4.2 above after each days flight.

9. **Approval**

This aircraft G-BXFI is approved for issue of a Permit to Fly provided that it is operated in accordance with the limitations and procedures contained in the Aircrew Manual and the FRC's referred to in section 6 above and those identified in section 8 above, plus the conditions of the Permit to Fly.

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10. **Maintenance**

This aircraft must be maintained by a company approved under BCAR A8-20 and rated for the aircraft type (and with consideration given to the ejection seats), in accordance with the AP Manuals and schedules referred to in Section 6 above and as agreed with the CAA Regional Office. In the event that the agreed arrangements are to be changed, the maintenance proposals will need to be reviewed and approved by the appropriate CAA Regional Office. The aircraft is to be kept hangared and inhibiting/short term care and maintenance procedures observed to prevent the onset of corrosion in the engine.

JC Barratt

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For the Civil Aviation Authority

Date 3 July 2008

Appendix M

ROYAL AIR FORCE CENTRE OF AVIATION MEDICINE

AIRCRAFT ACCIDENT HUMAN FACTORS REPORT

HAWKER HUNTER G-BXFI, SHOREHAM AIRSHOW, 22 AUGUST 2015

Appendix M (Cont)

Originator

Originator

	Accident Investigation and Human Factors Section
Head of Aviation Psychology	RAF Centre of Aviation Medicine
	RAF Henlow
	HENLOW
	SG16 6DN

Additional author(s)

	Accident Investigation and Human Factors Section
Aviation Psychologist	RAF Centre of Aviation Medicine
	RAF Henlow
	HENLOW
	SG16 6DN

The findings, conclusions and recommendations contained in this report are based on the evidence that was made available to the Accident Investigation and Human Factors Section, Royal Air Force Centre of Aviation Medicine (RAF CAM).

The report has been written prior to the final conclusions of the Air Accident Investigation Branch (AAIB) accident report.

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Contents

Acronyms and abbreviations

AAIB	Air Accident Investigation Branch
ATSB	Australian Transport Safety Bureau
ARM	Accident Route Matrix
CAM	Centre of Aviation Medicine
ft	Feet
G	Gravito-inertial forces
GPS	Global Positioning System
HEA	Human Error Analysis
HET	Human Error Template
HF	Human Factors
HFACS	Human Factors Analysis Classification System
hrs	hours
HTA	Hierarchical Task Analysis
kts	Knots
OC	Officer Commanding
PCM	Perceptual Cycle Model
RAF	Royal Air Force
SA	Situation Awareness
SHERPA	Systematic Human Error Reduction and Prediction Approach
TA	Task Analysis

Appendix M (Cont)

Introduction

1. RAF CAM was tasked by the Air Accidents Investigation Branch (AAIB) to investigate specific Human Factors (HF) aspects of the Hawker Hunter G-BXFI accident that took place at Shoreham Air Show on 22 August 2015. This report presents the results of the HF investigation.

Overview of accident

2. Hawker Hunter G-BXFI took off from North Weald Airfield in Essex at approximately 1200hrs on Saturday 22 August 2015. The aircraft transited to the South Coast and commenced the air display over Shoreham Airport at approximately 1220hrs. The aircraft performed a fly past at the display line, completed a “derry turn” to the left, and then entered a descending left turn reaching an altitude of 200ft.

3. The next manoeuvre was a bent loop, the aircraft climbing to reach an almost fully inverted position at the apex, at a height of approximately 2700ft. The aircraft accelerated through the descent, reaching a nose up attitude but had not achieved level flight before impacting the ground at the A27 road at approximately 1222hrs.

HF approach

4. **Evidence collection**. RAF CAM had access to the following evidence that was collected by the AAIB which provided the basis for this HF report:

a. In-cockpit video of accident sortie.

b. Observation of the aircraft wreckage at the AAIB hangar in Farnborough.

c. Observation of a Hunter T7 cockpit located at Bruntingthorpe.

d. Flight parameters identified by AAIB (including altitude, airspeed, and thrust during the display sequence).

e. G-BXFI pilot’s hand written in-flight notes which outlined a display sequence.

f. Flight trials report prepared by the AAIB’s Operations Advisor.

g. Notes from AAIB interviews undertaken with the G-BXFI pilot.

5. **Scope**. Following initial discussions with AAIB, three specific tasks were identified to be undertaken by RAF CAM with regards to the HF aspects of the accident. The tasks were:

a. **Task Analysis (TA) and Human Error Analysis (HEA)**. TA and HEA techniques would be used to analyse key decision points within the display sequence. The aim of this task was to understand the scope for human actions and/or decisions to have contributed to the accident sequence, and to analyse the nature of any errors that may be identified.

b. **Review of video evidence**. The aim of this task was to maximise the understanding of the pilot tasks and point of focus during the display sequence by reviewing the in-cockpit video.

c. **Review of pilot experience and task practice**. The aim of this task was to understand the nature of the recent, relevant, task practice undertaken by the pilot in the period leading up to the accident.

These tasks address particular areas in which AAIB wished to integrate specialist HF advice, rather than provide a full review of HF issues associated with the accident. Therefore, the results of the RAF CAM analysis should not be considered in isolation, but rather in the context of the wider investigation and other HF issues identified and reported by AAIB.

6. **TA and HEA**. Two key points in the accident sortie were identified through discussion with AAIB at which human action and/or decision making may have contributed to the accident. These two points were the decisions made on entry to the loop and at the apex of the loop. Two HEA approaches were applied to analyse each of these decision points:

a. **Systematic Human Error Reduction and Prediction Approach (SHERPA)**[1]. SHERPA is a technique for identifying the type of errors that could credibly occur, with the aim of developing methods for mitigating those errors. SHERPA is based on a Hierarchical Task Analysis (HTA) for the actions being assessed. Each task within the HTA is categorised according to the nature of the task and, dependent on that categorisation, a defined set of error terms are reviewed for credibility. Use of SHERPA provided a detailed analysis of the cognitive/decision making aspects of the task.

b. **Australian Transport Safety Bureau (ATSB) HF analysis of see and avoid**[2]. As a task requiring decision making based on visual information, the decisions analysed during the accident sortie had commonalities with the see and avoid task. Therefore, to provide an alternative to the traditional error analysis approach of SHERPA, the ATSB breakdown of the potential errors that can arise during see and avoid was adapted to the key decisions in the accident sequence. Applying the ATSB approach enabled a detailed analysis of the influence of perception on decision making during the accident sequence.

7. **Review of video evidence**. The in-cockpit video for the entry to the loop and the bent loop itself was reviewed. The overall phases of the manoeuvre were identified and a set of characteristics were defined for each second of video. These characteristics included pilot head movements, instrument panel contrast, position of sun, and control movements made.

8. **Review of pilot experience and task practice**. At the stage of issuing this report, RAF CAM has not undertaken the proposed analysis of pilot experience and task practice.

9. **HF analysis of findings**. The results of the video analysis and HEA were examined independently and in combination using the structure of the Accident Route Matrix (ARM)[3]. The ARM is based on the systematic and validated framework of the Human Factors Analysis Classification System (HFACS)[4] and aims to identify which factors, and at which point each factor, increased the risk of:

[1] Harris, D. Standon, N.A., Marshall, A., Young, M.S., Demagalski, J. and Salmon, P. (2005). Using SHERPA to predict design-induced error on the flight deck. *Aerospace Science and Technology*, 9, 525-532. The Human Error Template (HET) HEA approach was also used to examine decision making at the apex of the loop, but produced the same findings as SHERPA so was not used to analyse the decision making on entry to the loop.
[2] Australian Transport Safety Board (1991). *Limitations of the See and Avoid Principle*. Levels of Situation Awareness (SA) and the Perceptual Cycle Model (PCM) were also used to examine decision making at the apex of the loop but were of limited value due to the available evidence and so were not used to analyse decision making on entry to the loop.
[3] For a full description see: Harris, S. (2011). Human factors investigation methodology. *International Symposium on Aviation Psychology*. Available from: http://www.wright.edu/isap/.
[4] Weigmann, D.A. and Shappell, S.A. (2003). A Human Error Approach to Aviation Accident Analysis. Aldershot, UK: Ashgate.

a. **Hazard entry.** The probability the aircraft would have entered a hazardous scenario;

b. **Recovery.** The probability the aircraft would have successfully recovered;

c. **Escape.** The probability the pilot would have escaped without injury; and

d. **Survival.** The probability that personnel would have survived.

10. **Hazard sequence**. The four stages described in paragraph 9 are known as the hazard sequence. In the case of the G-BXFI accident, the HF analysis has focussed on understanding the actions that led up to hazard entry and decisions regarding recovery actions, with the aim of identifying the human actions that may have occurred and contributed to the accident. These results are described in the “Hazard Sequence” section of the report. Based on the hazard sequence analysis, key HF issues that would have made these actions more likely are identified and are summarised in the “Entry Conditions” section of the report.

Hazard sequence

11. This section of the report maps the sequence of actions during the flight that led up to the hazard entry against the associated HF analysis. As such, this section characterises what role human actions may have played in the accident sequence. Due to the limited availability of evidence regarding the accident (e.g. lack of flight data recorder or interview with the pilot regarding the accident sequence), it has not been possible to positively determine which of these actions and decisions were made. However, the analysis has identified the credible range of actions and decisions that may have occurred.

Entry into loop decision gate

12. **Decision gate**. At entry to the bent loop manoeuvre, a decision gate may have been used to determine if the parameters were suitable for the manoeuvre to be undertaken. The primary decision at this stage was if the airspeed was above the minimum required for the manoeuvre to be safely completed. The AAIB's Operations Advisor has stated that some pilots would adopt a 300kts minimum speed for a bent loop in a Hawker Hunter, whereas other pilots would adopt a 350kts minimum speed. At present, it has been estimated that the aircraft was travelling at 300kts to 310kts on entry to the loop. The different minimum speed criteria used by different pilots and uncertainty regarding the aircraft speed give rise to a number of possibilities regarding the decision to continue with the bent loop during the display sequence on 22 Aug 15 – as shown in Table 1.

Table 1: Nature of continue decision dependent on the aircraft speed and pilot decision criteria

Aircraft speed	Pilot used a 300kts minimum speed	Pilot used a 350kts minimum speed
299kts or below	Continue decision not in line with criteria	Continue decision not in line with criteria
300-349kts	Continue decision in line with criteria	Continue decision not in line with criteria
350kts or above	Continue decision in line with criteria	Continue decision in line with criteria

In interview with AAIB, the G-BXFI pilot stated that he used a 350kts minimum speed (except where circumstances demanded a "minimum height loop" in which case 350kts would be seen as a target speed). The aircraft speed was as estimated by AAIB (300-310kts) on entry to the bent loop was below 350kts. Therefore, it appears that the action to continue with the manoeuvre was not in line with the criteria that he used. Although there remains some uncertainty regarding the aircraft speed, an HEA has been undertaken on the assumption that the pilot used a 350kts minimum speed criteria and the aircraft airspeed was below this. Should this assumption be found to be incorrect, then the HEA presented below is invalid. The HEA has identified the potential for human error at each stage of the decision making process (as described in paragraph 6). It is not possible to determine which, if any, of these options took place based on the available evidence.

13. **Gathering information**. Limitations on gathering information about the aircraft speed could have led the pilot to have incomplete or inaccurate information about the speed at entry to the bent loop manoeuvre. Analysis of video evidence indicated that the pilot moved his head downwards towards the instrument panel 4 times in the 30 seconds prior to the pull up into the loop, suggesting that the pilot may have scanned his instruments during these times. However, there is not adequate information to determine if the airspeed indicator was read during these scans.

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a. **Information about aircraft speed not obtained**. The pilot may not have seen and/or read the airspeed when entering the loop manoeuvre. The airspeed may not have been read as a result of the scan pattern, the level of workload, the allocation of attention, change blindness, distraction, and/or visual limitations (such as contrast and glare)[5]. Although the pilot may have been aware that he had not obtained airspeed information, shortfalls in information gathering can occur without detection.

(1) **Scan pattern**. Video evidence indicated that the pilot was likely to have scanned the instruments during entry to the loop. However, it cannot be positively determined if the airspeed was scanned during this time. A pilot may learn or develop a poor scan technique which would increase the likelihood that the airspeed may not be read. The AAIB's Operations Advisor highlighted that airspeed is the primary focus on entry to a loop manoeuvre and so it would be expected that the airspeed indicator would form part of any instrument scan undertaken at this stage. Further information on the scan technique used by the pilot may provide insights on this matter.

(2) **Workload**. Both high and very low levels of workload can influence a pilot's visual search performance as these workload levels result in a reduction in the available attentional resources. It is considered unlikely that the pilot was experiencing very low levels of workload during the loop manoeuvre due to him having fewer total flying hours on the Hunter aircraft (compared to other aircraft types that he flew) and the demands imposed by display flying. However, these factors could give rise to high workload. High workload can affect the frequency of the pilot's visual scans and/or the duration of those scans. Thus a high level of workload could have increased the likelihood of airspeed information being missed.

(3) **Allocation of attention**. Attentional resources are limited and so if a pilot's attention is targeted at one particular area, this is likely to be at the expense of other areas. Therefore, if the pilot's attention was focussed on another part of the cockpit displays or outside the cockpit then information on the airspeed indicator could have been missed. Analysis of in-cockpit video indicated that the pilot's focus was predominantly on external cues to the left and upper left. However, the pilot was observed to move his head towards the cockpit instruments on a number of occasions prior to the manoeuvre. Therefore a failure to allocate any attention to the cockpit instruments is considered unlikely, although it is possible that limitations on attentional processes while looking towards the instruments could have led airspeed information to be missed.

(4) **Change blindness.** The pilot was observed to move head between external (left and upper left) and internal (downwards) cues. When there is a break in the observation of the target, for instance, when shifting attention between different areas, it is more difficult for changes occurring in one of those

[5] The scope for diffusion of responsibility, gravito-inertial (G) forces, obstructions, blind spot, accommodation, or visual narrowing to influence information gathering was reviewed but considered extremely unlikely to influence pilot behaviour in this instance. Although G on entry to the loop may have been sufficient to influence the pilot, the check of airspeed would occur before initiating the manoeuvre and so before this level of G was experienced. Diffusion of responsibility was not relevant as there was only one pilot in the cockpit, and so no other person with whom tasks could be perceived to be shared. The airspeed indicator could not be seen on the cockpit video and so it cannot be ruled out that it was obstructed, however, the position of the airspeed indicator within the cockpit means that it is unlikely that it was obstructed and review of the cockpit layout revealed it was not possible to obstruct the airspeed indicator with the stick controller. Due to the lack of obstructions, blind spot issues would not occur as binocular vision of controls was possible at all times. Accommodation was not considered relevant as the task to check the instruments would have been planned rather than alerted. Visual narrowing is addressed under the attentional focus and high workload points described in the main text.

areas to be detected – a phenomena known as “change blindness”. Therefore, it is possible that the pilot’s changed point of focus could have led a change to the airspeed on entry to the loop to be missed.

(5) **Distraction**. Distraction occurs when attention is diverted from the pilot’s primary focus to another source. Distraction can affect the frequency and/or duration of a pilot’s visual scan as the pilot re-focuses their attention elsewhere. Should the pilot’s attention be drawn away from the airspeed indicator on entry to the loop, then the information could have been missed.

(6) **Instrument contrast**. Instrument visibility can be influenced by the visual environment in which it is being viewed. The accident occurred on a bright, sunny day; in these environments, there can be areas of shadow which influence the visual contrast of controls. During the pilots head movements towards the instrument panel, the contrast changed, starting initially in shade, the top half of the instrument panel was then in sun for the second head movement, and then back into shade for the final two downwards head movements. The instrument panel appeared particularly dark during the last head movement. In these conditions, the pilot would have been adjusting his focus from a bright external view to a regularly changing instrument panel. The time taken to adjust from bright to shaded conditions can reduce visibility during this time.

(7) **Glare**. The presence of a glare source (in this case the sun) can have a significant impact on visual effectiveness[6]. The exact position of the sun in relation to the pilot during entry to the loop has not been calculated at this stage, but there is potential for glare to have made it more difficult to gather information from the displays.

b. **Inaccurate information obtained about airspeed**. As the pilot looked towards the displays during the entry to the loop, he may have looked at the airspeed indicator. However, he may have obtained an inaccurate perception of the airspeed, specifically, that the aircraft was faster than it actually was. Should the pilot obtain information that led him to believe the aircraft was faster than 350kts when it was not, then the subsequent action to continue with the manoeuvre would have been correctly made and implemented.

(1) **Airspeed indicator displayed the incorrect speed**. At present it is not known if the airspeed indicator was serviceable and displaying the correct speed on entry to the loop. Technical analysis is on-going by AAIB which may provide further information on this point. The airspeed indicator is the primary display used for speed information and so should this display have indicated that the aircraft was above 350kts then it would have led the pilot to believe the aircraft was at the correct configuration to continue with the manoeuvre.

(2) **Airspeed display misleading or ambiguous**. The airspeed display uses a moving pointer, with two scales one inside the other. On the first revolution, the pointer uses the outside scale to indicate speeds from 0 to 400kts, on the second revolution the pointer uses the inside scale to indicate speeds from 400kts to 750kts. Thus, the pointer indicates two speeds at any one time and the pilot will need to interpret which of these speeds is correct. For airspeed of approximately 300kts, the second dial would indicate approximately 750kts, which is above the maximum speed of the aircraft. Therefore, it is not

[6] Hawkins, F.H. (1987). *Human Factors in Flight*. Aldershot: Gower.

considered feasible that the pilot would have misread the inner dial as the actual aircraft speed.

(3) **Another dial read as airspeed**. The Hunter cockpit includes a number of moving pointer displays with rows of digits with a single pointer. While there are unique features of the airspeed dial which enable it to be discriminated from the other displays, the method of reading the airspeed display is similar to other displays which could lead to an error whereby another display was read as the airspeed. It has not been identified whether there was another display which would have been pointing to a position which could be misinterpreted as being a speed above the actual airspeed on entry to the loop.

(4) **Global Positioning System (GPS) read as airspeed**. The GPS within the G-BXFI cockpit displayed ground speed. Therefore, it is theoretically possible for the pilot to have read the GPS ground speed as the aircraft speed during entry to the bent loop. However, the AAIB's Operations Advisor has indicated that it is not feasible that the pilot would have used this figure rather than the airspeed indicator dial.

(5) **Airspeed was misread**. Moving pointer displays offer an acceptable ease of reading and are an effective means of presenting change over time and fluctuations around a level[7], but the nature of the pointer means that an exact reading is difficult to obtain and so there is a risk of error in reading the airspeed display[8]. Accuracy of reading displays can be influenced by workload and attention, but also by the pilot's expectation, in that the pilot sees what he or she expects to see, rather than what is actually presented. If the pilot was used to being above 350kts when checking the indicator on entry to the loop, then it could lead to such an expectation.

c. **Information about aircraft speed obtained at the wrong time**. The check of the airspeed indicator may have been mistimed so that it was undertaken either too early or too late. If the airspeed was checked during the downwards head movements, then it would have been checked at 26, 22, 14, and 7 seconds prior to pull up. Estimates of the indicated airspeed at these times (made by AAIB based on the in-cockpit video) are between 275kts and 313kts – all below the pilot's stated 350kts minimum entry speed. Therefore, while it cannot be positively determined when the airspeed was checked (assuming that it was checked – see earlier paragraphs), it is unlikely that the time at which the airspeed was checked could have led to an inaccurate perception of being above 350kts.

14. **Selecting course of action**. Had the pilot obtained accurate information about the aircraft speed at the entry to the loop, the next stage of the decision making process was to use that information to select a course of action. An error may have been possible at each stage of this process which could have led to a decision being made to continue with the manoeuvre at too slow a speed. These errors would have been made more likely by high workload and distraction (discussed in paragraph 13), which reduce the available cognitive resources and so increase the likelihood of error.

a. **Recollection of entry speed criteria**. While the pilot stated that he normally used 350kts minimum speed, it is possible that this criterion was not recalled correctly during the air display. If the pilot had incorrectly recalled a minimum entry speed of

[7] Kroemer, K.H.E and Grandjean, E. (1997). *Fitting the Task to the Human (fifth edition)*. London: Taylor and Francis.
[8] E.g. Kroemer and Grandjean (ibid); McCormick, E.J. and Sanders, M.A. (1982). *Human Factors in Engineering and Design (fifth edition)*. London: Mc-Graw-Hill.

300kts or below, or recalled 350kts as a target entry speed, it could lead him to believe that it was safe to complete the manoeuvre when at 300kts to 310kts.

b. **Recollection of options if too slow at entry**. It is not considered credible that the pilot was unaware of the option to not undertake the loop, but it was possible that the pilot recalled options to adjust the way the loop was flown to overcome a lower than desired airspeed. In interview with AAIB, the G-BXFI pilot indicated that if too slow on entry to a bent loop he would not pull up into the manoeuvre, due to the possibility of not having the airspeed to complete the loop. However, the pilot also described that he could select full power to accelerate early if speed was low. Analysis by the AAIB's Operations Advisor has concluded that the height at the apex of the loop is determined by a combination of the entry airspeed, engine thrust, the manner in which the pull-up is flown, and the extent of any bend to the loop. Therefore, it is possible that having identified a low speed the pilot may have intended to adjust the way in which the manoeuvre was flown to overcome the low speed on entry.

15. **Summary**. Analysis has been undertaken to identify the scope for human actions and/or decisions to have contributed to the entry to the loop being instigated below the pilot's stated minimum speed criteria of 350kts. It is not possible to determine which, if any, of these options took place based on the evidence available for the HF analysis, but the following accounts are considered credible and feasible:

a. The airspeed may not have been seen or read when entering the loop manoeuvre as a result of scan pattern, high workload, allocation of attention, change blindness, distraction, and/or visual limitations (such as contrast and glare).

b. An inaccurate perception of the airspeed may have been obtained, specifically, that the aircraft was faster than it actually was, as a result of the airspeed indicator displaying an incorrect speed, another dial in the aircraft being read as the airspeed, and/or the airspeed dial being misread.

c. The minimum speed required on entry to the loop may have been recalled incorrectly.

d. The pilot may have selected to continue with the bent loop but adjust the way the manoeuvre was flown to overcome the low speed on entry.

Loss of thrust on climb

16. **Issue**. Analysis undertaken by AAIB has identified that there was a reduction in thrust during the climb component of the bent loop. It was not known at the time of writing this report what caused the loss of thrust (such as pilot action, technical fault, etc) and so no HF analysis has been undertaken of it. However, in the course of the analysis of the in-cockpit video it was considered whether the pilot was aware of the loss of thrust and, if so, when. Such analysis assumes that the loss of thrust was not initiated by the pilot intentionally. If subsequent work by AAIB identifies that the pilot intentionally reduced thrust during the climb, then the analysis presented in paragraphs 17 and 18 is invalid.

17. **Detection during climb**. During the climb, the pilot's point of focus was on the external cues, looking left and briefly to the right twice. Video evidence indicated that the pilot's head did not move downwards towards the instrument panel during the climb. The AAIB's Operations Advisor has indicated that there would have been few clear indications on the climb to the loss of thrust, either on the instruments or in the other characteristics of the

aircraft's flight. Therefore, it is considered unlikely that the loss of thrust was detected during the climb.

18. **Detection at apex**. The airspeed and altitude at the apex of the loop may have provided a cue to the loss of thrust. At the apex of the loop the pilot's head moved from an external point of focus towards the cockpit instruments. Therefore, there was scope for the pilot became aware of the loss of thrust at the apex. It cannot be positively determined if the pilot became aware of the loss of thrust at this stage but, if he were aware of it, the loss of thrust could have increased workload and been a source of distraction from that point in the sortie onwards.

Apex of loop decision gate

19. **Decision gate**. At the apex of the loop, a decision gate may have been used to determine if the parameters were suitable for the manoeuvre to be completed. The primary decision to be made at this stage was if the height was above the minimum required, but the aircraft speed would also be considered. The Flight Test report from the AAIB's Operations Advisor has indicated that the absolute minimum height required for the loop to be completed successfully and the aircraft to capture a 500ft height on exit would have been between 3100ft and 3450ft. In interview with AAIB, the G-BXFI pilot indicated that he used a minimum height at apex of between 4000ft and 5000ft. 4000ft was described as a "minimum height loop" (comprising 3000ft to complete the loop, 500ft for the height on exit, and an additional 500ft to act as a safety buffer) which was only used in some circumstances. On a typical display the pilot stated that he used a minimum apex height of 4500ft to 5000ft. The G-BXFI pilot also stated that the speed at apex would be acceptable between 100kts and 150kts, but at 100kts control of the aircraft would be reduced. At present it has been estimated that the aircraft reached a maximum altitude of 2700ft at the apex of the loop at airspeed of 100kts, which is below the minimum height outlined above for the manoeuvre to be completed safely and lower than the pilot's desired airspeed. At this altitude, it would have been necessary to perform an escape manoeuvre to avoid impact with the ground; therefore, analysis has been undertaken of the decision to continue with the loop when below the pilot's stated minimum height criteria. The potential for human error at each stage of the decision making process has been reviewed and the following options identified. It is not possible to determine which, if any, of these options took place based on the available evidence.

20. **Gathering information**. Limitations on gathering information about aircraft height could have led the pilot to have incomplete or inaccurate information about the altitude at the apex of the loop. Analysis of video evidence indicated that just prior to reaching the apex of the loop the pilot's focus was to the right and up. Then, through the apex of the loop the pilot looked down, to the left and up, down and to the right and up, before looking forward and up. Such a range of head movements indicate that the pilot was actively engaged in gathering information at the apex of the loop and looked towards the instruments on at least two occasions. However, there is not adequate information to determine if the altimeter was read during these times.

a. **Information about aircraft height not obtained**. The pilot may not have seen and/or read the altimeter when at the apex of the loop. The altimeter may not have been read as a result of the scan pattern, the level of workload, the allocation of attention, distraction, or visual limitations (such as contrast and glare)[9]. As was

[9] The scope for G forces, diffusion of responsibility, obstructions, blind spot, accommodation, or visual narrowing to influence information gathering was reviewed but considered extremely unlikely to influence pilot behaviour in this instance. G forces were discounted as the level of G force estimated at the apex of the loop was too low to have influenced visual search.

highlighted in relation to the airspeed on entry to the loop, although the pilot may have been aware that he had not obtained height information, shortfalls in information gathering can occur without detection due to the role of expectation.

(1) **Scan pattern**. Video evidence indicated that the pilot was likely to have scanned the instruments at the apex of the loop. However, it cannot be positively determined if the altimeter was scanned during this time. A pilot may learn or develop a poor scan technique which would increase the likelihood that the altimeter may not be read. The AAIB's Operations Advisor has stated that the scan pattern used in swept-wing high-speed aircraft, such as the Hunter, differs from that used in other aircraft classes, due to the increased importance of altitude. Therefore, if the pilot was trained and was more experienced on another platform which uses a different scan pattern, there may be a risk of altitude information being missed. Scan technique would be developed through training and experience and so further information on the pilot's background may provide additional insights on this matter.

(2) **Workload**. As identified in relation to the decision making on entry to the loop (paragraph 13), it was possible that the pilot was experiencing a high level of workload during the display which could have increased the likelihood of altitude information being missed.

(3) **Allocation of attention**. Attentional resources are limited and so if a pilot's attention is targeted at one particular area, this is likely to be at the expense of other areas. During the bent loop sequence, it is necessary for the pilot to shift attention between the external view and the cockpit instruments. Analysis of the in-cockpit video indicated that the pilot's focus was being shifted in line with this requirement – with a primary focus on external cues and two head movements downwards while at the apex of the loop. Although the overall allocation of attention appeared to be in line with task requirements, it is not possible to determine whether the allocation of attention to the cockpit displays was adequate to enable altitude information to be gathered. The allocation of attention during the bent loop sequence could, therefore, have led altitude information to be missed.

(4) **Distraction**. As identified in relation to the decision making on entry to the loop (paragraph 13), it was possible that distraction led the pilot's attention to be drawn away from the altimeter. If indications of a loss of thrust were detected during the instrument scans, these could have been a source of distraction and so a reduced likelihood of altitude information being gathered. In addition, the AAIB's interviews with the G-BXFI pilot indicate that he expected the airspeed at the apex of the loop to be higher than that achieved during the accident sortie (100kts), such an unexpected figure on one display could have distracted the pilot from gathering information about altitude.

(5) **Instrument contrast**. Instrument visibility can be influenced by the visual environment in which it is being viewed (as highlighted in paragraph 13). During the pilot's head movements towards the instrument panel, the displays were in dark shade. As a result, the pilot would have had to adjust his eyes from the bright external view to the dark instrument panel. The time taken to adjust from bright to shaded conditions can reduce visibility during this time.

Obscuration of the altimeter by the stick controller is possible, but only when the stick controller is moved to the left; such a movement of the stick controller was not required at this stage of the manoeuvre and so is considered unlikely. Diffusion of responsibility, blind spot, accommodation, and visual narrowing were discounted for the same reasons described in footnote[5].

(6) **Glare**. The presence of a glare source (in this case the sun) can have a significant impact on visual effectiveness (as highlighted in paragraph 13). During the bent loop manoeuvre the position of the sun changed in relation to the pilot and, therefore, there is scope for glare to have made it more difficult to gather information from the displays.

b. **Inaccurate information obtained about aircraft height**. As the pilot looked towards the displays at the apex of the loop he may have looked at the altimeter. However, he may have obtained an inaccurate perception of the aircraft height, specifically, that the aircraft was higher than it actually was. Should the pilot obtain information that led him to believe the aircraft was above the minimum required height when it was not, then the subsequent action to continue with the manoeuvre would have been correctly made and implemented (albeit based on inaccurate information).

(1) **Altimeter displayed the incorrect altitude**. At present it is not known if the altimeter was serviceable and displaying the correct altitude during the loop. Technical analysis is on-going by AAIB which may provide further information on this point. The altimeter is the only display of height available in the cockpit and so should this information have indicated that the aircraft was above the gate height then it would have led the pilot to believe the aircraft was at a safe height to continue with the manoeuvre.

(2) **Altimeter display misleading or ambiguous**. The AAIB's Operations Advisor has described an issue with altimeters of the type used in the Hunter, that when changing digits for 1000s ft, the drum may be at a position partially between the previous and next 1000ft altitude (for instance, in the process of moving between 2000ft and 3000ft). Should G-BXFI suffer with this issue, it is feasible that the altitude information presented to the pilot was ambiguous or misleading, resulting in the pilot reading the altimeter as being 1000ft higher than it was. A 1000ft difference in altitude could position the aircraft close to the minimum required height at the apex, which could lead to a perception that the aircraft was at a safe height to continue with the manoeuvre. Technical analysis is on-going by AAIB which may provide further information on this point.

(3) **Altimeter was misread**. It was considered whether another dial within the cockpit could have been misread as being the altimeter. However, the altimeter is unique amongst the displays in that it presents the altitude using a numeric drum (showing 1000s and 100s ft) and a single needle (for 100s ft and below). Given the different method of reading the altimeter compared to the other dials it is unlikely that the pilot had read another display as the altimeter. Digital displays are generally associated with a lower level of reading errors than moving pointer displays. However, there remain some instances of reading error in experimental studies[8] and in reading aircraft altimeters of the type found in G-BFXI[10]. The risk of such error may have been increased at certain altitudes as the pointer can obscure the digit display when it is between the 700ft and 800ft markers. At present it has been estimated by AAIB that the aircraft reached a maximum altitude of 2700ft. Therefore, there is scope that the digit drum could have been obscured by the pointer at the apex of the loop increasing the likelihood of the altitude being misread. Accuracy of reading displays can also be influenced by workload, distraction, and expectation (paragraph 20).

[10] Hemmingway, J.C. (1980). Altimeter reading and setting errors as factors in aviation safety. In *NASA Aviation Safety Reporting System: Quarterly Report No. 12*. NASA Technical Memorandum 81252.

Misreading the altimeter could have led the pilot to believe that the aircraft was at a safe height to continue with the manoeuvre.

c. **Information about aircraft height obtained at the wrong time**. The check of the aircraft altimeter may have been mistimed so that it was undertaken either too early or too late. Such mistiming could have led to the pilot estimating the height at the apex, which would have been subjective and so at an increased risk of error than directly reading the altimeter. If the altitude was checked during the downwards head movements, then the video analysis indicated that altitude was checked at the appropriate time. While a check of height at the wrong time cannot be ruled out (as it is possible that the pilot checked the displays without moving his head) the video evidence suggests that this error is unlikely.

21. **Selecting course of action**. Had the pilot obtained accurate information about the aircraft height at the apex of the loop, the next stage of the decision making process was to use that information to select a course of action. An error may have been possible at each stage of this process which could have led to the manoeuvre being continued when at too low a height. These errors would have been made more likely by high workload and distraction (discussed in paragraph 20) which would reduce the available cognitive resources and so increase the likelihood of error.

a. **Recollection of gate height**. The pilot may have recalled the minimum height at apex incorrectly. While the pilot stated that he used a 4000ft to 5000ft decision criterion, it is possible that this criterion was not recalled correctly during the air display. If the pilot had incorrectly recalled a gate height of 2800ft or below, it could lead the pilot to believe that it was safe to complete the manoeuvre when too low.

b. **Knowledge of options if too low at apex**. The pilot may have not known the option to undertake the escape manoeuvre if too low at the apex of the loop, or may have recalled another option to recover the aircraft. In interview with the AAIB, the G-BXFI pilot described a method of recovering from either low height or low airspeed, but stated that at both a low height *and* low airspeed (as occurred in the accident sortie) a roll out manoeuvre would not be successful. Such knowledge would have arisen through formal guidance (such as procedures and documents), training, and experience. In interview, the G-BXFI pilot stated that he had not performed unusual position recovery training in the Hunter and, while unusual position recovery had been discussed, he could not recall discussing recovery from 100kts while inverted. The pilot also commented that rolling the Hunter at 100kts was not in line with his understanding of the information in the Hunter aircrew manual. If, at the apex of the loop, the pilot believed an escape manoeuvre would not be successful then it is unlikely that the pilot would decide to take this action.

c. **Decision made to continue with manoeuvre**. It was possible that, despite being at a lower height than the decision gate, the pilot decided to continue with bent loop. Such a decision is considered credible if the pilot believed that it would be possible to complete the manoeuvre safely from the lower height. However, in interview with the AAIB the G-BXFI pilot stated that he believed that the aircraft needed 3000ft to successfully complete the loop. Therefore, it is not considered credible that the pilot believed he could safely complete the loop when below 3000ft.

d. **Decision regarding course of action made too late**. The AAIB's Operations Advisor's Flight Test Report has indicated that 4 seconds were available from the apex of the loop in which to implement the escape manoeuvre. 4 seconds is an adequate period of time to make rule-based decisions and implement practiced actions. However, it is too short a period of time to engage in complex decision making and implement novel actions[11]. The G-BXFI pilot's comments regarding his knowledge of options if too low and at low speed at the apex indicate that the selection of this escape manoeuvre could not be characterised as rule-based or practiced, resulting in a requirement for a longer decision time. Therefore, it is possible that the pilot was not able to identify a suitable course of action within the window available to do so. Such a delay to decision making could have led to the aircraft entering a flight profile from which impact with the ground was unavoidable.

22. **Summary**. Analysis has been undertaken to identify the scope for human actions and/or decisions to have contributed the loop being continued when below the pilot's stated minimum height at the apex. It is not possible to determine which, if any, of these options took place based on the evidence available for the HF analysis, but the following accounts are considered credible and feasible:

a. The altimeter may not have been seen or read at the apex of the loop as a result of scan pattern, high workload, allocation of attention, distraction (for instance, from detecting a loss of thrust during the climb or the airspeed being lower than expected), and/or visual limitations (such as contrast and glare).

b. An inaccurate perception of aircraft height may have been obtained, specifically, that the aircraft was higher than it actually was as a result of the altimeter displaying the incorrect altitude, a misleading or ambiguous display of the altimeter digit drum, the altimeter digit drum being partially obscured, and/or the altimeter being misread.

c. The minimum height required at apex may have been recalled incorrectly.

d. An escape manoeuvre may have not been selected as a result of the limited time available to select and implement the action, and the guidance and training that the pilot received with regard to rolling out of an inverted loop in the Hunter.

[11] Leach, J. (2004). Why people 'freeze' in an emergency: temporal and cognitive constraints on survival responses. *Aviation Space and Environmental Medicine*, 75, 539-542.

Entry conditions

23. The HF analysis of the hazard sequence outlined in the previous section has identified a range of credible actions and decisions that may have contributed to the accident. The likelihood of these actions and decisions would be increased by factors present before the day of the accident. In the language of RAF CAM's accident investigation approach (the ARM), these factors are known as "entry conditions". The HF analysis undertaken by RAF CAM of the G-BXFI accident has focussed on specific aspects of the accident, and so has not identified the broad range of entry conditions that contributed to the accident. The main text of the report has described some potential entry conditions regarding training and experience of recovery manoeuvres, design of cockpit displays, and instrument scan pattern training. Given the important role of entry conditions in influencing behaviour on the day of an accident, the results of the RAF CAM analysis must not be considered in isolation, but rather in the context of the wider investigation and the factors prior to the day that have been identified and reported by AAIB.

Appendix N

Mandatory Permit Directive 2011-001

MPD No: 2001–001

UNITED KINGDOM
CIVIL AVIATION AUTHORITY

MANDATORY PERMIT DIRECTIVE

The following action required by this Mandatory Permit Directive (MPD) is mandatory for applicable aircraft registered in the United Kingdom operating on a UK CAA Permit to Fly.

MPD : 2001-001 ROLLS-ROYCE

Subject: Engine calendar life limits.

Applicability: Rolls-Royce Avon Mk 1, 100 and 200 Series engines.

Reason: Following an investigation into a fatal accident to a Hawker Hunter on 5 June 1998, the Air Accidents Investigation Branch have recommended that consideration be given to imposing calendar life limits on fuel and air systems fitted on Avon engines, since these systems may be subject to ageing effects.

It is recognised that ageing effects may not be confined solely to fuel and air systems. Corrosion of discs and blading, for example, may also be time dependent. The CAA has experience of accelerated corrosion occurring on engines fitted to aeroplanes of low usage, and the possibility of an age related failure to either the control units or core engine cannot be discounted.

The CAA has reviewed calendar life limits imposed in military service for the Avon series. In later years of operation UK (MOD) imposed calendar limits which varied between 10 and 20 years, depending on the mark number. Operation of these aeroplanes in civil operation however, may not be representative of military use, due to comparatively low utilisation of the type on the civil register and the application of a limit as high as 20 years is not considered appropriate.

Since the safety record for a substantial portion of the Avon fleet in military service was achieved with calendar limits imposed, it is considered that limits are appropriate for engines fitted to aircraft issued with a CAA Permit to Fly. This MPD introduces calendar life limits for Avon Mk 1, 100 and 200 Series engines. These limits are in addition to Group A part cyclic life limitations and overhaul limits already specified for these engines.

Compliance: Before 1 October 2001 achieve compliance with the following actions. Thereafter, compliance must be established at each renewal of the Permit to Fly for the aeroplane.

continued overleaf

Enquiries regarding this MPD should be made to the United Kingdom Civil Aviation Authority, Applications and Certification Section, Safety Regulation Group, Aviation House, Gatwick Airport South, West Sussex RH6 0YR. Telephone: +44 (0)1293 573149 Telefax: +44 (0)1293 573993.

Appendix N (Cont)

MPD No: 2001-001 Page 2 of 2

1 Establish from engine records the date of last engine recondition or overhaul.(i.e. the last shop visit at which the engine was zero timed). This date may be taken as the day of dispatch from the facility in which the recondition/overhaul was carried out. If the engine was stored in accordance with the manufacturer's instructions immediately after recondition/overhaul , this date may be taken as the day upon which the engine was removed from storage.

2 Remove from service all engines which have been fitted for more than 15 years since either the date of last recondition/overhaul, or the termination of the subsequent storage period.

3 Engines and associated control systems removed from service as a result of this limitation may not be refitted until they are reconditioned/overhauled in accordance with manufacturer's instructions.

Alternative Means of Compliance:

The intent of this MPD is to prevent potential calendar time related engine deterioration developing to a point where engine integrity is compromised.

The CAA will consider alternative inspection/test and sampling programmes which can be shown to prevent unacceptable deterioration of engines in service. Operators may wish to propose such programmes in lieu of engine withdrawal from service. These programmes must, however, be underwritten by an approved BCAR A8-20 organisation or the manufacturer and must address all ageing related deterioration which could occur on the Avon engine series.

Record compliance with this MPD in the aircraft log book.

This MPD becomes effective on 18 May 2001.

Appendix O

Leaflet 70-80: Guidance Material for Ageing Engine Continuing Airworthiness

Leaflet 70-80 Guidance Material for Ageing Engine Continuing Airworthiness

1 Introduction

1.1 This guidance material has been produced following a number of accidents over a period, involving the serious failure of high calendar time engines or their accessories. Over a prolonged calendar time engine parts risk deterioration due to corrosion and the hardening of materials such as seals, gaskets, diaphragms and flexible pipes. This leaflet has been compiled to accommodate historic engine types and their ancillary equipment which are typically without manufacturer-recommended calendar time backstops available.

1.2 The intention of this guidance is to provide continuing airworthiness recommendations for the management of engines against potential calendar time related deterioration. This is particularly relevant to certain categories of non-EASA aircraft types where the product is no longer actively supported by the engine manufacturer. If the Original Equipment Manufacturer (OEM), does not provide any recommended calendar time between overhauls, under a low utilisation operation regime, this can result in an engine remaining on wing for a protracted period before removal for workshop strip/overhaul under the TBO limit (in hours or cycles run). This guidance provides a framework of generic best practices as examples of how to allow ageing engines to continue to operate with acceptable standards of continuing airworthiness.

2 Applicability

2.1 This guidance is intended specifically for the following categories of fixed and rotary wing aircraft and engines:

a) Non-EASA aircraft types with National Certificates of Airworthiness powered by gas turbine engine(s) or by radial piston engine(s) of > 400 hp;

b) Ex-military aircraft with National Permits to Fly powered by gas turbine engine(s) or radial piston engine(s) of > 400hp.

Complex aircraft types and their engines, however, are not covered by this guidance material.

2.2 While aimed at a specific group of high calendar time engines, owners and operators of other high time engines can consider the practices and the need for additional maintenance actions to ensure appropriate standards of continuing airworthiness are upheld. The principles laid out in this document may be useful for this purpose.

3 Engine Manufacturer's Recommendations

3.1 Typically ageing and ex-military engines do not have calendar time recommendations between overhaul quoted in the manufacturer's instructions for continuing airworthiness. Any limitations that have been imposed by the OEM, however, must be respected, such as whole engine and critical part hard lives, and cycle/hour times between overhaul, whichever come first. Furthermore, ancillaries must be controlled within their OEM recommended lives.

Other instructions such as maintenance tasks, frequencies and inspections, as well as those for ancillary equipment should be respected.

4 The Maintenance Organisation (MO) Environment

4.1 In the context of ex-military Permit to Fly aircraft and National Certificate of Airworthiness aircraft with large radial piston or gas turbine engines (as defined in paragraph 2, titled Applicability, above) it is expected that the aircraft will be maintained by a suitably approved organisation (such as a BCAR A8-20/A8-23 approved maintenance organisation, or appropriate equivalent). This organisation will accordingly have responsibility for the control of engine records (including storage), hazard analysis and management of scheduled tasks within the Maintenance Schedule including a regular review of the effectiveness of the programme.

5 Hazard Risk Assessment

5.1 BCAR A8-20/A8-23 appropriately approved maintenance organisations can where applicable conduct a hazard risk assessment on the continuing airworthiness aspects of the operation of engines with prolonged calendar lives since new or last overhaul to establish the levels of maintenance required. Potential areas of consideration can include but not be limited to:

a) Multiple engine and system applications with adequate redundancy and safety margin;

b) The safety record of the specific type, taking into account UK and worldwide events, the specific failure modes and their consequences;

c) The likelihood of any safety critical failure modes such as in-flight fire, uncontained failure or propeller release;

d) The consequences of the loss of thrust of a single engine;

e) Any systems or measures which can realistically be used to mitigate against the consequences of a significant failure event.

If a Hazard Risk Assessment (HRA) is carried out as a means of compliance against this guidance material a formal review process should be carried and a documented report compiled.

6 Alternative Means of Compliance

6.1 In the absence of OEM calendar time limitations on engine overhaul periods, Table 1 illustrates the option either to remove from service engines which have reached or exceeded 20 years of service since last recondition, overhaul or termination of last accepted storage period, or through an appropriately approved organisation (e.g. BCAR A8-20 Maintenance Organisation), construct a customised Alternative Means Of Compliance (AMOC) programme.

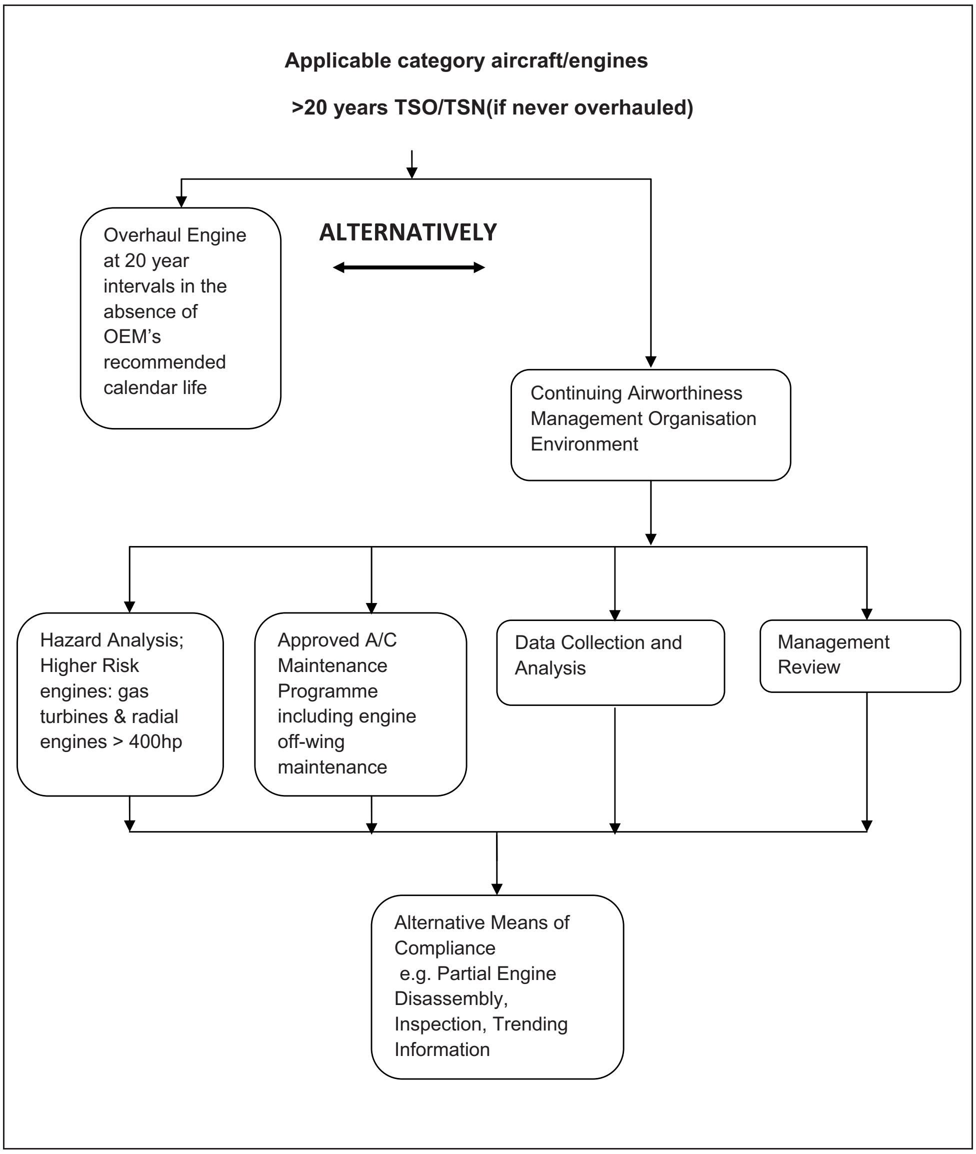

Figure 1 Fixed Calendar Time Overhaul and Alternative Means of Compliance Options

6.2 It is possible that AMOCs could include a broad spectrum of in-service monitoring, inspection and partial disassembly actions (which may vary across different engine types) to verify that acceptable standards are being maintained, and to ensure that age-related deterioration is addressed. The basic elements and considerations of an AMOC are covered in the sections below.

7 Maintenance Programmes/Schedules

7.1 It is considered important that the MO compiles a customised Maintenance Programme (MP) that reflects all engine on-wing and off-wing scheduled AMOC maintenance such as inspections, trend monitoring, workshop visits, and partial disassemblies where necessary. An MP should include references to the OEM's data such as manuals, instructions, bulletins and service letters where applicable. Similarly any modification or de-modification status should be reflected.

7.2 The scheduled engine maintenance and inspection tasks that constitute the AMOC (including those required to be carried out off-wing, in a workshop) should be integrated with the higher level aircraft MP.

7.3 The elements needed for a particular programme aimed at developing an AMOC will depend upon the outcomes of the hazard assessments, data collection, analysis and review functions as outlined in Table 1 of paragraph 6.1 above. Paragraphs 8 and 9 below detail some generic items which might be considered for inclusion in any possible programme, but it is accepted that the details of each individual programme will vary depending on the results of the preparatory work and the specific issues pertinent to the type being reviewed.

8 Gas Turbine Engines – Generic or Possible AMOC Elements

8.1 Particularly relevant for gas turbine engines, where possible the following data could be considered for collection at each engine run, as permitted by the type:

a) Pilot reports;

b) Oil consumption rates/trend monitoring;

c) Gas path performance trend monitoring

d) (e.g. TGT, spool speed, etc.);

e) Engine run down times;

f) Vibration monitoring (if system equipment is fitted);

g) Engine running times (including ground runs).

8.2 The above information should be formally recorded as relevant for each flight, and issues such as gas path parameters, vibration, and oil consumption trending plotted for evidence of datum shifts. It is quite likely that the optimum health monitoring could be carried out by flight crew at a steady state phase of engine operation.

8.3 Further maintenance tasks relevant to the AMOC may not be limited to those listed below as follows:

a) Borescope inspections of gas path components;

b) Hot section inspections (with or without combustor removal);

c) Compressor inspections with compressor half case removal;

d) Oil filter element sectioning and analysis;

e) Oil analysis (i.e. SOAP);

f) Fuel contamination checks;

g) Magnetic Chip Detector (where fitted) findings and recorded history;

h) Jet pipe inspections for corrosion, cracking (particularly of circumferential welds) and evidence of damage;

i) Bleed valve check/inspection;

Appendix O (Cont)

j) Module changes;

k) Compressor water washes under OEM's instructions.

8.4 Inspections should clarify which areas and how the inspection is to be carried out. For example compressor inspections should clarify whether rotating blades, static vanes and rotor path linings are inspected, and at which stages. If engine design and the manufacturer's instructions permit, then periodic compressor inspections, with the top casing removed, allow for a more thorough inspection to be carried out. Similarly, combustor-can removal could provide a useful insight into the status of combustor and initial turbine stage conditions. Inevitably, some inspections may require the removal of the engine from the airframe.

An example of possible generic AMOC inspections for consideration on gas turbine engines is provided below.

Zones	**Gas Turbine Engine – Inspection Type**	**Frequency ***
Compressor Inlet	Visual inspection (where possible) of compressor inlet for signs of FOD and corrosion.	Monthly/pre-flight daily
Axial Compressor Stages as far as is practical	Borescope blades through IGV, vanes and rotor path linings of stages as far as possible, for corrosion, damage and deterioration.	3-12 Monthly
All stages of compressor	Detailed visual inspection of all compressor stages (blades, vanes and linings) with compressor top casing removed, for corrosion, damage and deterioration.	2-6 yearly
Combustion chamber and burners	Check for erosion, corrosion, hot spots and deterioration of all cans and burners. Also for evidence of symmetrical flame pattern, streaking and coking.	2-4 yearly
HP Turbine	Check HPT blades and vanes for erosion and heat damage, with combustor cans removed.	2-6 yearly
LP Turbine	Check LPT blades and vanes for erosion and heat damage, utilising access from the jet pipe.	3 monthly
Jet Pipe	Detailed visual inspection for damage or age- related deterioration.	3 monthly
Jet Pipe	FPI or suitable alternative NDT inspection of welded areas for signs of deterioration.	3 yearly
Bleed Valves	Visual inspection for corrosion.	6 monthly
Oil and Fuel Filter Replacement	Remove, section and analyse filter elements for evidence of contaminants – sending deposits away for analysis and plot findings where applicable.	12 monthly
Spectrometric Oil Analysis Programme	SOAP oil analysis.	6-12 monthly
Ancillary Equipment	Remove for overhaul, disassembly or bench test ancillary components (such as , pumps, fuel control units, etc.).	4-6 yearly
Flexible Hoses	Inspect, replace, pressure test in accordance with OEM's recommendations. CAP 562 Book 2, Leaflet 20-50 provides some generic test details.	2-8 yearly

***NOTE:** The task frequencies given above are only intended as generic guidelines in the absence of any recommendations or specific inspections from the manufacturer. Furthermore, the intervals should not supersede reduced repeat inspection intervals that may be required to monitor any permitted deterioration within the approved limits of certain parts.

Findings resulting from the above tasks should be documented in the aircraft records for future reference when carrying out periodic reviews of the effectiveness of the implemented programme.

Appendix O (Cont)

9 Large Radial Piston Engine – Generic or Possible AMOC Elements

9.1 Along similar lines to the operation of gas turbine engines, the following data should be collected following the operation of large radial engines, such as:

a) Pilot reports;

b) Oil consumption rates/trend monitoring;

c) Engine running times (including ground runs);

9.2 Additional piston engine checks and inspections could include but not be limited to the following:

a) External engine inspection including crankcase and cylinder inspections;

b) Cylinder compression including differential pressure checks;

c) Borescope Inspection;

d) Oil and fuel analysis;

e) Engine power checks;

f) Checks for evidence of hydraulicing.

9.3 Tasks involving partial engine disassembly to ensure against the onset of the effects of age deterioration could include the following:

a) Removal and inspection of cylinder heads;

b) Removal and inspection of cylinders;

c) Disassembly of pistons, gudgeon pins and connecting rods for condition inspection;

d) Crankshaft inspection in-situ;

e) Crankcase inspection in-situ.

An example of additional generic AMOC inspections for consideration on large radial piston engines is shown below.

Zones	**Large Radial Piston Engine - Inspection Type**	**Frequency ***
Engine Externals	General Visual Inspection of the cylinders and crankcase including baffles for corrosion, cracking, heat distress, leaks etc.	12 monthly
Cylinder Compression Check	Compression check where applicable and in accordance with manufacturer's instructions, recording the results.	12 monthly
Cylinder Valves	Carry out cylinder valve clearance check for all cylinders.	12 monthly
Sample Cylinder Removal	Remove master cylinders (where applicable) from each bank plus other sample cylinders (alternating at each maintenance opportunity where possible) and carry out detailed visual inspection of internal cylinder bore and components such as pistons, master rod, connecting rod assys, gudgeon pin internal bores for evidence of wear and age related deterioration.	6 yearly
Internal Crankcase	Check internal crankcase for evidence of oil sludge and moisture.	6 yearly

Zones	Large Radial Piston Engine - Inspection Type	Frequency *
Cylinder Borescope	Carry out internal borescope inspection of each cylinder via spark plug hole, recording and assessing the condition of valves, piston crown, cylinder head and cylinder walls.	12 monthly
Engine Oil Condition	Send sample of engine oil for SOAP oil analysis Remove, inspect and clean oil sump plugs and oil screens as applicable.	12 monthly
Engine Filters/ Screens	Replace, section and examine fuel and oil filter elements where applicable for evidence of debris. Collect filter debris for inspection, analysis and future reference.	12 monthly
Power Runs	Carry out engine ground power assurance check.	12 monthly
Ancillary Equipment	Remove for overhaul, disassembly and bench test ancillary components (such as magnetos, carburettors, pumps, control units etc).	4-6 yearly
Crankshaft/ Reduction Gear Assembly	Carry out in-situ inspection of crankshaft/reduction gear assembly for signs of corrosion, cracking deterioration (e.g. along propeller attachment splines), viewing as much of the crankshaft as is accessible or possible.	3-6 yearly or at propeller removal opportunity (whichever is soonest)
Flexible Hoses	Inspect, replace, pressure test flexible hoses in accordance with OEM's recommendations. CAP 562 Book 2, Leaflet 20-50 provides some generic test details.	2-8 yearly intervals
Cylinder Base Nut Check	Break torque check on cylinder bolts, to ensure bolts are not backing off.	3 yearly

***NOTE:** The task frequencies given above are only intended as generic guidelines in the absence of any recommendations or specific inspections from the manufacturer. Furthermore, the intervals should not supersede reduced repeat inspection intervals that may be required to monitor any permitted deterioration within the approved limits of certain parts.

Findings resulting from the above tasks should be documented in the aircraft records for future reference when carrying out periodic reviews of the effectiveness of the implemented programme.

10 Utilisation of Approved Maintenance Organisations

10.1 Appropriately approved maintenance organisations (e.g. BCAR A8-20/A8-23) are required to carry out all maintenance tasks (whether in the AMOC or otherwise) in accordance with the OEM's maintenance manual instructions.

10.2 It is acknowledged that some of the tasks involved in engine continuing airworthiness may have transitioned in the AMOC package from the dedicated workshop (where these tasks were originally carried out) into the aircraft base maintenance environment. The maintenance organisation has responsibility to ensure that all staff involved in the engine maintenance activity (including the AMOC) are assessed and controlled for appropriate experience, competence and training to carry out the tasks prescribed. Whatever the task, the maintenance organisation should ensure that it has available the appropriate tooling and equipment, approved data and contamination free environment to carry out any engine maintenance operations (including those requiring partial disassembly and complex activities).

11 Safety Critical Tasks

11.1 Whenever multi-system maintenance is carried out on aircraft systems including engines, fuel etc, the Maintenance Organisation shall establish procedures to minimise the risk of multiple errors by individual maintenance personnel during a single line or base activity (the principles of BCAR A8-23 paragraph 15.2 c) refer).

12 Engine Records

12.1 The retention of full engine records is necessary for the confidence of the continuing airworthiness programme. Therefore, the following issues should be accommodated:

a) Details of last restoration or overhaul (dates etc.) activities;

b) Completion of engine operation hours and cycles in log books (including for ground running);

c) Strict disc, drum and shaft (i.e. critical part) life logging and controls within the framework of OEM declared lives;

d) Evidence of compliance with Mandatory Permit Directives (MPDs) and Airworthiness Directives (ADs) as applicable;

e) Retention of maintenance workpack details;

f) Engine storage details – compliance with OEM's instructions (refer to 13.1 below for clarification).

13 Engine Storage

13.1 Installed engines which are used only infrequently should be either run periodically or inhibited and stored in accordance with manufacturer's instructions. Removed engines should be stored and sealed as detailed by the engine OEM's recommendations. Maintenance organisations regularly involved in the storage and inhibiting of engines should consider establishing procedures and work sheets based on the manufacturer's instructions, which include maintaining the engine storage status within the records. Engine log books and records should clarify the dates and extent of system inhibition/de-inhibition, providing details where relevant.

14 Periodic Review

14.1 MOs wishing to utilise the AMOC option should periodically review the effectiveness of their reliability programmes by utilising findings and feedback data as well as workshop findings/strip reports on a regular basis, as formalised under their organisation's procedures.

15 AMOC Management

15.1 It is the responsibility of the appropriately approved Maintenance Organisation (e.g. BCAR A8-20/A8-23 or equivalent) to manage the AMOC package (under its privileges) as an alternative to a 20 year calendar life to recondition or overhaul the engine in a workshop environment, and to reflect all elements of the package within the aircraft level Maintenance Programme.

16 Mandatory Permit Directive (MPD) and Airworthiness Directive (AD) Compliance

16.1 Where the guidance information provided in this leaflet conflicts with an MPD or an AD (either already in existence or in the future) against an aircraft/engine type, the MPD/AD must still be complied with.

Appendix P

Mandatory Permit Directive 2016-002

Safety Directive

Civil Aviation Authority

MANDATORY PERMIT DIRECTIVE

Civil Aviation Authority

Number: 2016-002

Issue date: 7 October 2016

In accordance with Article 41(1) of The Air Navigation Order 2016, as amended, the following action required by this Mandatory Permit Directive (MPD) is mandatory for applicable aircraft registered in the United Kingdom operating on a UK CAA Permit to Fly.

Type Approval Holder's Name:	**Type/Model Designation(s):**
Rolls-Royce	Avon Mk 1 and 100 Series Engines

Title:	**Engine Stage 1 - 4 Compressor Blades and Discs - Inspection**
Manufacturer:	Rolls-Royce
Applicability:	Avon Mk 1, Avon Mk 100 series
Reason:	CAA has been notified of a complete loss of thrust event on an Avon 100 series powered aircraft as a result of a compressor blade failure. The failure has occurred in a blade pin-hole attachment lug and was initiated by corrosion leading to subsequent fatigue. This region of the blade is below the platform and cannot be inspected by any in-situ inspection permissible under AMOC to MPD 2001-001. Other blades in the set were cracked due to corrosion and there have been other reports of corrosion initiated fatigue leading to failure in the forward stages of these engines in military service. The manufacturer developed modifications for protection of the blade attachment lugs during military operation. The failure occurred on an engine with a modification incorporated but over the extended time period of operation, which was not foreseen at the time the modification was developed, the protection had broken down and was no longer effective in protecting the pin-holes from corrosion. Compressor blade failure results in total thrust loss and, depending on flight phase, may result in loss of the aircraft. This MPD is raised to require an inspection of blade lugs on the first 4 stages of Avon Mk 1 and 100 series compressor blades. The discs are also to be inspected. This inspection requires engine removal and at least partial disassembly.
Effective Date:	**Date of revocation of CAA Safety Directive SD-2015/003 which requires all operators of Hawker Hunter aircraft on the UK civil register to cease all flying operations. This MPD will be revised to state the actual effective date when the Safety Directive is revoked.**

Appendices

Appendix P (Cont)

Compliance/Action:	1. This MPD is published in the expectation that the Hunter Safety Directive will be revoked. That decision has yet to be taken. 2. Determine from engine records when the engine was last overhauled. For any engine which exceeds 20 years since last overhaul, carry out the following inspections within 6 months or 20 flight hours from the effective date of this MPD, whichever limit is reached first. For any engine with less than 20 years calendar time since last overhaul on the effective date of this MPD, carry out the inspections when the engine reaches 20 years since last overhaul. **<u>Note:</u>** The inspections specified may only be carried out by a BCAR A8-23 approved organisation with a B1 Turbine Engine rating and the capability to carry out Rolls-Royce Avon series engine partial strip or overhaul under their terms of approval. 3. Remove the engine from the airframe in accordance with published aircraft manual instructions. Carry out a partial strip of the compressor in accordance with engine overhaul manual requirements to permit inspection of the individual stage 1-4 blades and discs. Visually inspect individual blades and discs against manual limits permitted for further processing. Reject from service any blades or discs which do not satisfy these limits. 4. Carry out cleaning and NDT inspection of all remaining blades and discs in accordance with manual requirements or other inspection process approved by CAA. Reject from service all stage 1 to 4 blades and discs which do not pass corrosion acceptance limits or NDT inspection. 5. For remaining serviceable blades, protect stage 1-4 blade pin holes by applying protective coating in accordance with manufacturer's published data or other method approved by CAA. 6. Reassemble the engine incorporating serviceable blades and discs in accordance with engine manual requirements. Re-install and carry out a pass-off run in accordance with airframe manufacturer's published data. 7. Repeat inspect stage 1-4 blades and discs at intervals not to exceed 5 years, if the engine hour Time Between Overhaul limit has not been reached in that time. The above tasks do not constitute a full overhaul of the compressor or the engine and the Time Since Overhaul may not be re-set as a result of this shop visit. If operators wish to carry out a complete engine overhaul at this point then to qualify as a newly overhauled engine the complete overhaul cycle as defined in the relevant manufacturer's overhaul manuals must be accomplished by an appropriately approved BCAR A8-23 organisation with B1 rating with Avon 1 or 100 series overhaul capability.

Appendix P (Cont)

ENSURE COMPLIANCE WITH THIS MPD IS RECORDED IN THE AIRCRAFT LOGBOOK	
Reference Publications:	Nil
Remarks:	1. This MPD was posted on 16 March 2016 as PMPD 16-02 for consultation until 30 March 2016. 2. If requested and appropriately substantiated, the CAA may accept Alternative Methods of Compliance to this MPD. Application for an Alternative Method of Compliance (AMOC) must be made to the CAA and, if agreed, the CAA will issue a written acceptance that confirms the AMOC meets the necessary compliance requirements. 3. Enquiries regarding this Mandatory Permit Directive should be referred to: GA Unit, Civil Aviation Authority, Safety and Airspace Regulation Group, Aviation House, Gatwick Airport South, West Sussex RH6 0YR. Telephone: +44 (0)1293 57 3988 E-mail: ga@caa.co.uk

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Unless otherwise indicated, recommendations in this report are addressed to the appropriate regulatory authorities having responsibility for the matters with which the recommendation is concerned. It is for those authorities to decide what action is taken. In the United Kingdom the responsible authority is the Civil Aviation Authority, CAA House, 45-49 Kingsway, London WC2B 6TE or the European Aviation Safety Agency, Postfach 10 12 53, D-50452 Koeln, Germany.

Aircraft Accident Report 1/2017

Report on the accident to
Hawker Hunter T7, G-BXFI
near Shoreham Airport
on 22 August 2015