ACCIDENT

Aircraft Type and Registration:	Yak-52, G-YAKB
No & Type of Engines:	1 Ivchenko Vedeneyev M-14P radial piston engine
Year of Manufacture:	1992 (Serial no: 9211517)
Date & Time (UTC):	8 July 2016 at 0934 hrs
Location:	1 nm north of Dinton, Wiltshire
Type of Flight:	Aerial work
Persons on Board:	Crew - 2 Passengers - None
Injuries:	Crew - 1 (Fatal) 1 (Serious) Passengers - N/A
Nature of Damage:	Aircraft destroyed
Commander's Licence:	Commercial Pilot's Licence
Commander's Age:	60 years
Commander's Flying Experience:	2,953 hours (of which 446 were on type) Last 90 days - 18 hours Last 28 days - 15 hours
Information Source:	AAIB Field Investigation

Synopsis

The aircraft was conducting a flight for a test pilots' school. The commander, a civilian flight instructor, was in the rear seat and a tutor from the school occupied the front seat.

Shortly after completing a series of aerobatic manoeuvres, the engine lost power without warning. Attempts to restore power were unsuccessful and, at about 1,100 ft agl, the commander committed to a forced landing in a field. Evidence showed that the pilots probably became aware of a farm strip late in the approach to the intended field and made an attempt to land on the strip. The forced landing was unsuccessful and the aircraft struck the ground in a steeply left banked attitude at the southern edge of the strip. The tutor was fatally injured and the commander sustained serious injuries.

The cause of the loss of engine power was not determined, but the reported symptoms were indicative of a fuel system problem.

One Safety Recommendation is made concerning the maintenance of seat belts and harnesses.

Background information

The aircraft was operating under a contract with a test pilots' school at Boscombe Down (BD), Wiltshire. The work was sub-contracted to a Flying Training Organisation (FTO). The FTO had further sub-contracted the work to the aircraft's commander, a civilian flight instructor, who was experienced on the Yak-52.

The aircraft was being employed for a Qualitative Evaluation (QE). This is part of the Test Pilots' course where different aircraft types are brought to BD, under contract, for short-term use. This gives the test pilot students and flight test engineer students experience of multiple aircraft types and the opportunity to fly a test scenario with a 'safety pilot' (the aircraft's commander). The Yak-52 was used to expose the students to an Eastern European aircraft. There was also a requirement for 'tutors'[1] from the school to experience flying the aircraft type.

The Yak-52's commander had participated in QEs, with a Yak-52, annually since 2010. He occupied the rear seat when flying with test pilot students and the front seat when flying with flight test engineer students.

On Sunday 3 July 2016, G-YAKB was flown from its base to BD by the commander with the exercise tutor who had organised the QE. The following day the commander and exercise tutor flew a flight profile similar to a QE, prior to the commander flying with the students. This was to demonstrate to the commander BD's local procedures and a QE sortie profile. The flight did not include any simulated emergencies. Later that day the commander also gave a 90-minute Technical and Safety Briefing on operating the aircraft, which included a cockpit familiarisation, to all the students and the exercise tutor. This briefing was deemed mandatory for any tutor intending to fly the Yak-52. The front seat pilot (FSP) on the accident flight, who was a tutor and a Royal Air Force (RAF) pilot, was not present at the briefing.

The AAIB investigation into this accident was conducted in parallel to, but independently of, a military Service Inquiry (SI) investigation. The SI investigation was launched because of the death in service of an RAF pilot. The SI investigation focussed more on the organisational and operational aspects of the test pilots' school and its oversight by the Ministry of Defence. The SI investigation report was published by the Defence Safety Authority on 15 June 2017[2].

Footnote

1 Test Pilot instructors at the school are called tutors.
2 https://www.gov.uk/government/publications/service-inquiry-into-the-aircraft-accident-involving-yak52-g-yakb-on-8-july-2016

History of the flight

This section was compiled using a combination of radar data, BD ATC radio recordings, witness statements and the commander's own recollection.

Prior to the flight

The FSP had originally been scheduled to fly in the Yak-52 late in the morning of the accident, after a student. However, the student was unfit to fly and so the FSP's flight was rescheduled to be the first flight of the day.

On the day of the accident the commander and FSP were described as being "bright and breezy" when they arrived at the school, with the FSP looking forward to the flight, not having flown the aircraft type before. The pilots were seen briefly in discussion before a meteorological brief and again afterwards, for about 15 minutes, prior to being "out-briefed" by the supervisor for the flight.

The aircraft had been kept overnight in a hangar; upon arrival, the pilots helped push the aircraft out onto the apron. The assisting engineer commented that they appeared rushed. The aircraft was then refuelled to about 1 cm below the brim, with a fuel uplift of 53 litres being recorded in the fuel bowser logbook.

The accident flight

After an uneventful start up and taxi out, the aircraft took off from Runway 23 at 0915 hrs[3], departing to the west of BD and climbing initially to about 5,200 ft amsl. It completed some aerobatic manoeuvres, between 3,400 ft and 5,200 ft amsl, some of which involved inverted flight, which the commander believed[4] were flown by the FSP. The pilots remained on the BD ATC Approach frequency throughout the flight.

The commander stated that after completing these manoeuvres, when the aircraft was at about 4,000 ft amsl and in a slow descent, the engine lost power without warning. The propeller continued to windmill. During this time the commander exercised the throttle, but this had no effect. He then returned the throttle to approximately its original position, which he believed was about 70% rpm. On checking the engine instruments he noted that the fuel pressure indication was zero. Believing that there may be a stuck "flapper valve" in the fuel lines, the commander took control and flew some high g turns to try to release the valves, but to no avail.

On the assumption that the engine-driven fuel pump had failed, the commander instructed the FSP to turn the fuel primer handle[5] to the left position and pump it in a bid to restart the engine[6]. He initially observed him doing so and recalled that the FSP was pumping at a rate of about once every 3 to 4 seconds. With each pump the engine started and

Footnote

[3] All times in this report are UTC.
[4] The commander had an incomplete recollection of events during the flight.
[5] See *Fuel system description* for a detailed description of the fuel system.
[6] See *Yak-52 emergency procedures* below for the engine failure in flight checklist.

accelerated momentarily, with associated power, before stopping again. The commander observed the fuel pressure increasing with each pump of the primer. During each restart attempt the engine sounded normal, with no additional noises that might have indicated a mechanical problem.

The commander continued to fly the aircraft while the FSP pumped the fuel primer handle and made radio transmissions to BD ATC when required. At 0930:32 hrs the FSP transmitted a MAYDAY stating "WE HAVE A MAJOR MAJOR MALFUNCTION", before requesting radar vectors to return to the airfield. ATC acknowledged this and advised the aircraft to turn onto a heading of 090° M. Shortly thereafter, ATC asked the aircraft to squawk the transponder emergency code of 7700, to which the FSP replied "UNABLE". At 0931:30 hrs, the FSP asked ATC for a range from BD; they replied 12 nm. At 0932:06 hrs, the FSP radioed that they were visual with the ground and "…PROBABLY GOING TO BE ER PFL'ING [practice forced landing] TO A FIELD ER WEST OF BOSCOMBE". At this point the aircraft was at 3,100 ft amsl (about 2,650 ft agl) and 10.5 nm from BD. ATC then transmitted the surface wind at BD, which was from 230° at 14 kt; this was acknowledged by the FSP.

The commander stated that at this point he had elected to continue towards BD, in case the engine recovered, while the FSP continued to pump the primer handle. The aircraft continued to descend throughout this time. Shortly thereafter, ATC informed the crew that the aircraft's range was 9 nm. Realising that the aircraft would not be able to reach BD, at 0933:29 hrs, at an altitude of 1,475 ft amsl (approximately 1,100 ft agl), the FSP transmitted "GOLF KILO BRAVO IS MAY [SIC] PFL'ING TO A FIELD JUST TO THE WEST OF BOSCOMBE [SLIGHT PAUSE] ER WILL PHONE YOU ON THE GROUND." This was the last transmission received by ATC. Figure 1 shows the radar track of the flight.

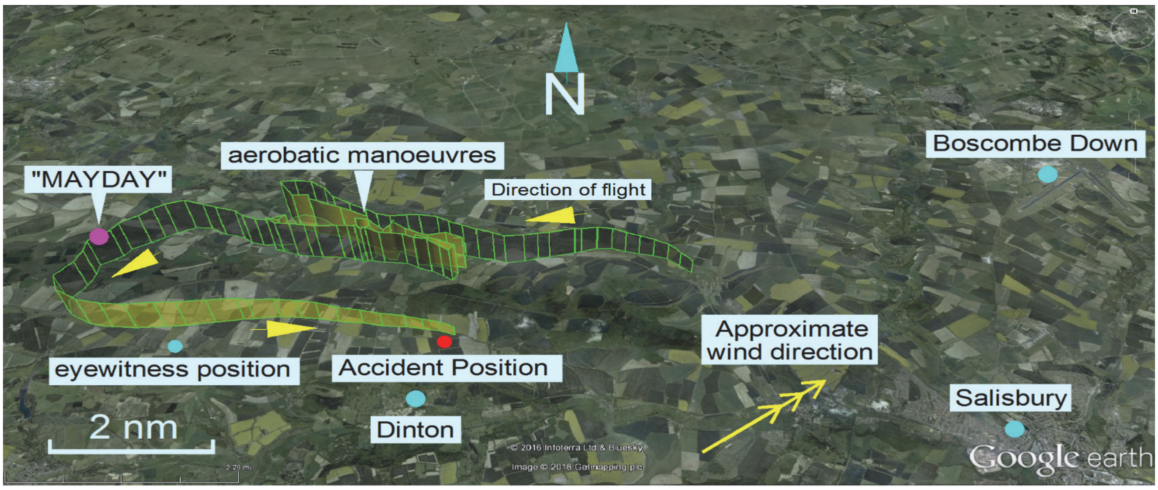

Figure 1

Radar plot of the flight (Clee Hill radar data)

Having decided to perform a forced landing, a large wheat field was identified and an approach to it established. During the approach a farm strip came into view and the commander had an "incomplete memory" that one of them had declared "there is an airstrip there", which was ahead and to the left. He stated that it would have been his decision to try to land on the strip as opposed to the chosen field. Figure 2 shows the relative positions of the final radar points and the accident site.

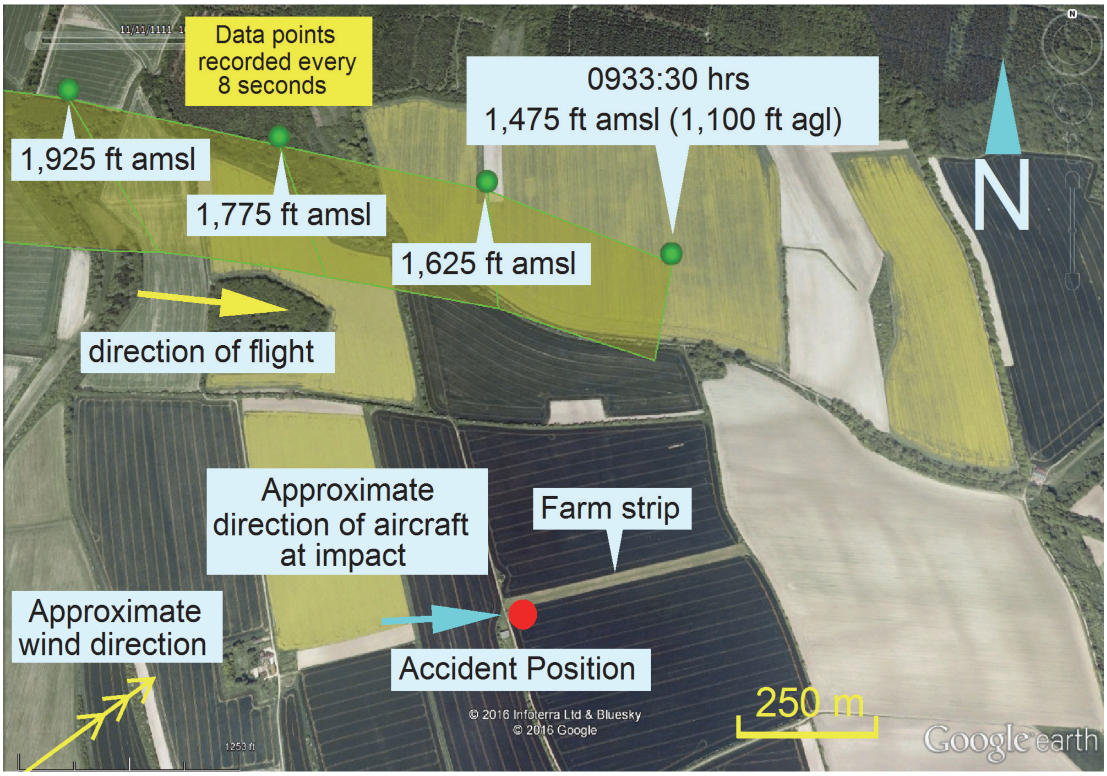

Figure 2

Final radar points (Clee Hill radar data)

The commander could not recall in which direction the aircraft turned after the last radar position, nor whether it was positioned to the north or south of the strip.

The attempt to land on the strip was unsuccessful and the aircraft struck the ground on the southern edge of the farm strip with its left wingtip, in a steeply banked attitude. The front of the fuselage broke up during the ground impact and the FSP was thrown clear of the aircraft.

A BD-based helicopter was operating in the vicinity around the time of the accident. On hearing the FSP's last transmission, the helicopter commander informed ATC that they were able to offer assistance and the helicopter was directed towards the aircraft's last radar position. Once visual with the Yak-52 on the ground, the helicopter landed close by and one of its pilots went to offer assistance to the Yak pilots. The FSP was lying unresponsive, close to the aircraft, and the commander, who was seriously injured, was in the rear seat. The helicopter pilot stated that the Yak-52 commander said to him "there was a landing strip wasn't there?" and that they came in steeply and he had to level off.

Another BD helicopter subsequently arrived, followed by two air ambulances and a Search and Rescue helicopter. Soon after, two local police officers (who attempted to resuscitate the FSP), the Rescue and Fire Fighting Services (RFFS) from BD and the local authority arrived at the accident site, as did an ambulance. The FSP was subsequently pronounced deceased at the scene. The commander was flown to hospital by air ambulance.

Eyewitness account

At about 0930 hrs, an eyewitness about 3 nm west of the accident site saw an aircraft just to the north, travelling in an easterly direction, on a constant heading. He stated that the aircraft was about 1,000 to 1,500 ft agl, above some low cloud. The engine sounded as though it was faltering; it then died completely before restarting again for a period of 4 to 5 seconds at high power. It then faltered again and stopped. The witness did not hear the engine start again. He was visual with the aircraft throughout this time. It then disappeared from his view because of cloud cover and some large trees.

Accident site

The aircraft wreckage was located in a wheat field on the southern edge of a private farm strip, 1 nm north of Dinton, at an elevation of 436 ft amsl (Figure 3). The private strip was not shown on any aeronautical chart or in any airfield guide and, according to its owner, was not easily visible from the air. The strip was 473 m long, 20 m wide and orientated in the direction 080°(M).

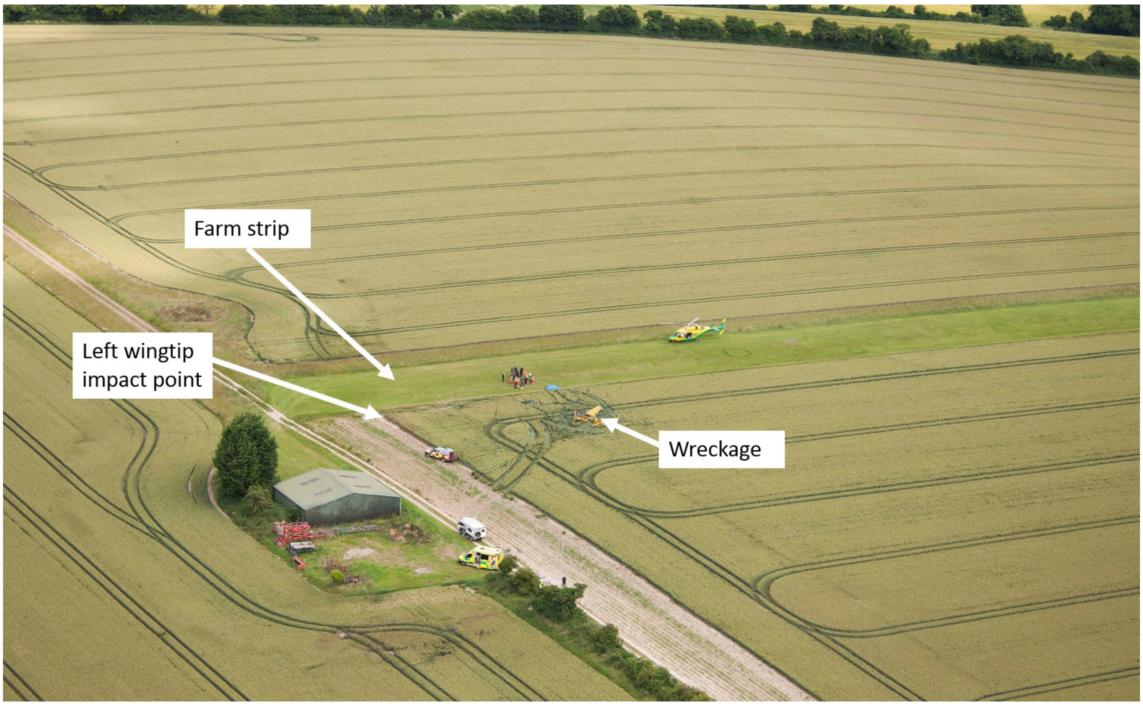

Figure 3

Aerial view of accident site (looking north) and private farm strip
(Photograph courtesy QinetiQ)

The ground impact marks showed that the aircraft had struck the ground left wingtip first, in a steep left bank; this was followed by a heavy nose impact (Figure 4). The aircraft had then bounced backwards, probably striking its tail, before bouncing again into the location where it was found, resting upright, 35 m from the initial impact point.

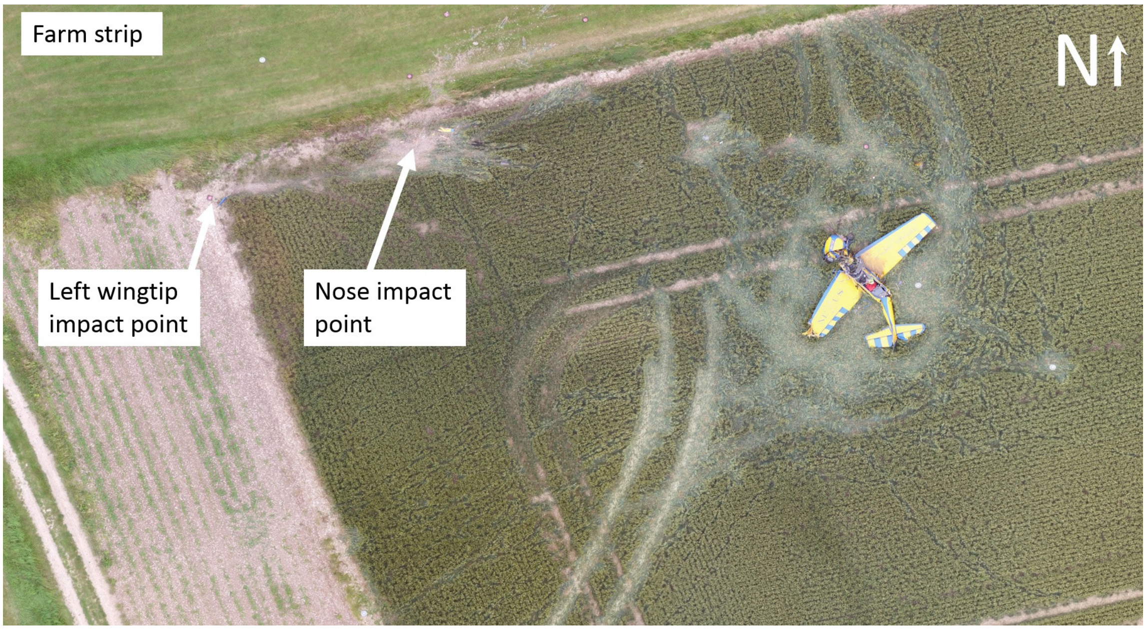

Figure 4
Aerial view of accident site (North up)

Recorded information

Final flight path

Radar data for the accident flight was recorded by various radar stations. The final secondary radar return, recorded at 0933:30 hrs by the Clee Hill radar (Figure 5), placed the aircraft on a bearing of about 025° from the accident site. At this point the aircraft was at 1,475 ft amsl[7] (1,100 ft agl) and approximately 0.32 nm (590 m) from the accident location. The last RT transmission was almost coincident with the final radar point. For the segment between 2,600 ft amsl and the final radar point, the average ground speed was 108 kt and the estimated average airspeed of the aircraft was 90 kt (167 km/hr), based on a wind from 264° at 18 kt[8].

Footnote

[7] This altitude was derived from Mode S transponder data which is transmitted in 25 ft increments.
[8] Derived from the Met Office information obtained from a weather balloon released at 0900 hrs from Larkhill, about 9 nm north-east of the accident site.

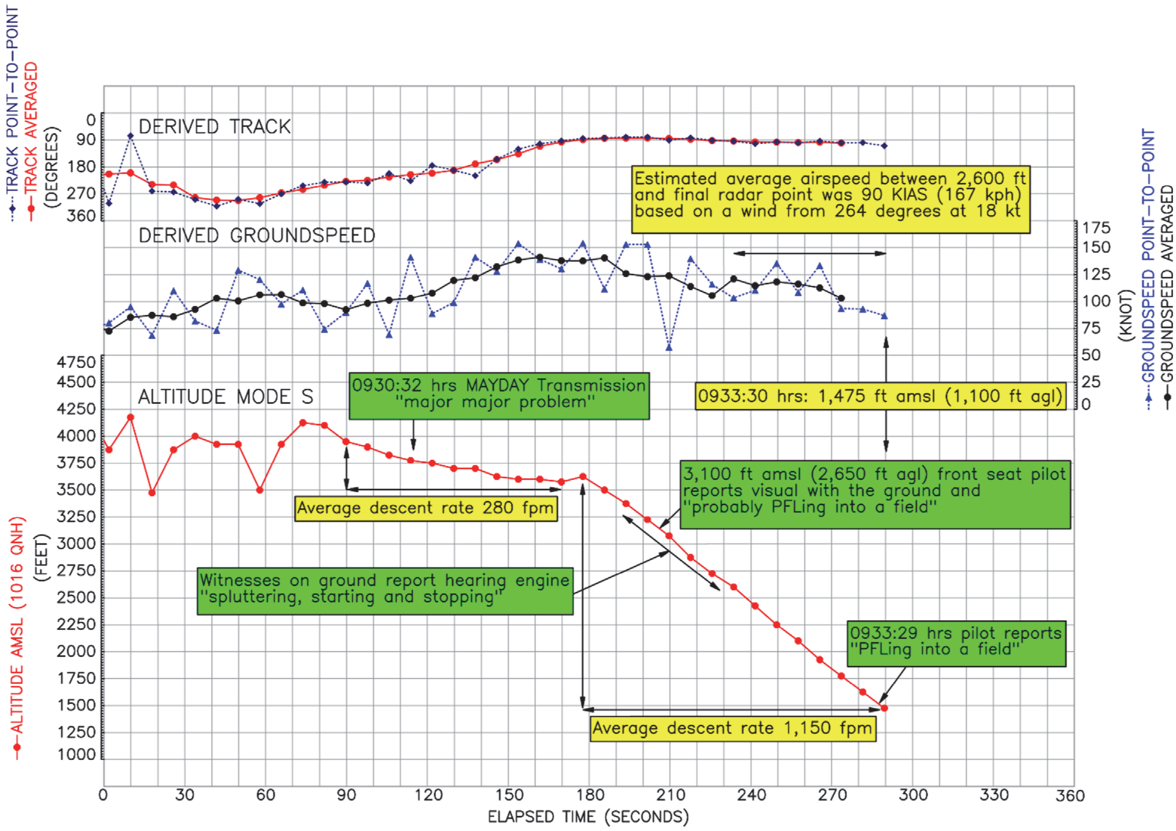

Figure 5

Accident flight radar data from the Clee Hill radar

Commander's comments

The commander was visited by the AAIB in hospital eight weeks after the accident and interviewed 12 weeks after the accident.

The commander stated that as the forward visibility from the rear cockpit was "very poor" he briefed some FSPs that, during a forced landing into a field, he would hand over control to them at an appropriate time, dependent on the situation, for them to do the landing. He had no recollection of who had control for the accident landing, though it is possible he handed control to the FSP. If this was the case, he believed he would have done so when the aircraft was straight on the final approach. He also said that the rpm gauges in both cockpits were intermittently serviceable during the QE week.

Although the rate of pumping of the primer handle did not allow the aircraft to maintain height, he did not ask the FSP to pump faster. The commander could not recall whether the FSP ceased pumping once the wheat field had been chosen for the landing.

Additionally, he had no recollection of the wind at BD, or if ATC had transmitted it after the MAYDAY was declared. He also had no recollection of what he had said to the helicopter commander after the accident.

Pilots' experience and qualifications

Commander

The commander held a current Flying Instructor rating and a Display Authorisation. He first flew the Yak-52 in March 2005, achieving a total of 446 hours on type at the time of the accident. He stated that about 80% of his Yak-52 hours were in the front seat, as the majority of his flying was competing in aerobatic competitions and display flying.

Prior to the 2016 QE, the pilot had last flown the Yak-52 on 16 March 2016, for one hour. His most recent logged experience in the Yak-52 prior to this was in July 2015, during the 2015 QE.

The commander had completed three successful forced landings in Yak-52s following previous engine failures. All of these had ended with the aircraft landing on a grass strip or an airfield, with the landing gear extended. He had landed the aircraft from the front seat on all three occasions. He had demonstrated PFLs onto an airfield from the rear seat when instructing on the Yak-52, but had not performed an actual forced landing from the rear seat.

The commander stated that he would normally conduct an off-airfield PFL to a minimum height of 500 ft agl and his target speed for forced landings in a Yak-52 was 180 km hr (97 kt). While this is greater than the published best glide speed of 160 km hr, he felt it was better to fly faster as it gave him more flexibility.

The commander had last supervised and/or demonstrated a PFL in a Yak-52, from the rear seat, during an instructional sortie on 16 March 2016.

Front seat pilot

The FSP was a qualified service pilot, test pilot and Qualified Flying Instructor. He also held a current ATPL (A) with Single Engine Piston (SEP) (Land) and Flight Instructor Ratings. He had a total of 5,773 military flying hours and 518 civilian flying hours. He had flown 62 hours in the preceding 90 days and 17 hours in the preceding 28 days.

His civilian logbook indicated that he last supervised and/or demonstrated a PFL on 5 June 2016 in a Diamond DA40 D, a SEP aircraft with side-by-side seating.

He had not flown the Yak-52 prior to the accident flight.

Test pilot students' comments

The AAIB interviewed several of the test pilot students and engineers who flew in the aircraft before the accident. They stated that the front and rear cockpit rpm gauges did not work, or did not work properly, and communications via the intercom and radio were of a poor quality. One added that the heading and attitude indicators in the rear cockpit were not working, the former of which was unserviceable before the QE commenced.

The extent of the emergencies brief given by the commander, before each flight, varied from, "if anything went wrong, he would take control and deal with the emergency" to "he specifically mentioned actions to be taken by the student in case of engine malfunctions that could not be performed by the pilot in the back seat". Another stated that the commander also talked about what the controls did and what the gauges showed, mentioning that the rpm gauge did not work properly. Others could not recall what was said.

Two of the test pilot students stated that they recalled performing all of the landings (about two to three each) from the front seat at BD and the commander did none from the rear.

Meteorology

An aftercast provided by the Met Office stated that there was a slow-moving cold front lying over the area of the accident, moving south-east. Surface observations from Larkhill[9] and METARs from MoD Boscombe Down[10] reported BROKEN stratus cloud between 600 and 900 ft agl at first, with bases lifting and cloud thinning later.

A radiosonde balloon released from Larkhill at 0900 hrs provided full details of the wind direction and speeds through the lower atmosphere. Table 1 shows some of the balloon's recorded wind data:

Wind direction and speed (kt)	Height of reading (GPS)
240°/10	133 m/436 ft
261°/16	471 m/1,545 ft
266°/19	604 m/1,980 ft
270°/24	793 m/2,602 ft

Table 1

Recorded wind data

Medical and pathological information

The FSP's post-mortem examination was carried out by a consultant histopathologist. Of note, he had serious head and facial injuries and fractures in his arms and hands, with his right hand more severely injured than his left. Additionally, he had serious injuries to the lower part of his legs.

Toxicological analysis of blood samples detected two antihistamine drugs which are used for the treatment of allergies such as hay fever. The levels indicated a previous, but not recent use. It was likely that this drug was taken at least 36 to 48 hours earlier and should not have had any detrimental effect on the FSP's ability to fly the aircraft.

Tests for alcohol were negative.

Footnote

9 Larkhill is about 433 ft amsl and 9 nm north-east of the accident site.
10 Boscombe Down Airfield is 407 ft amsl.

The post-mortem report concluded that he had died as a result of multiple traumatic injuries resulting from the accident.

Operational information

Permit to Fly

G-YAKB did not have a Certificate of Airworthiness but was operating on a Permit to Fly (PTF). The rules under which it must operate are in CAP 393, *Air Navigation: The Order and Regulations* (ANO). The extant version, published in 2015, stated:

> ***'23 Limitations of national permits to fly***
>
> *(1) Subject to paragraph (3), an aircraft flying in accordance with a national permit to fly must not fly for the purpose of:*
>
> …
>
> *(c) aerial work other than aerial work which consists of flights for the purpose of flying displays, associated practice, test and positioning flights or the exhibition or demonstration of the aircraft*[11]*.*
>
> *(2) No person may be carried during flights for the purpose of flying displays or demonstration flying (except for the minimum required flight crew*[12]*), unless the prior permission of the CAA has been obtained.*
>
> *(3) An aircraft flying in accordance with a national permit to fly may fly for the purpose of aerial work which consists of instruction or testing in a club environment if it does so with the permission of the CAA.*
>
> …'

The commander stated that he believed the aircraft was performing aerial work at the test pilots' school by way of demonstration flights, not instructional flights. He added that while he had not read the ANO he had been told it was acceptable to do demonstration flights in an aircraft with a PTF. Given this, and the fact that the flights were for the school, he believed this was appropriate.

The FTO that had sub-contracted the pilot stated that they did not believe approval to do aerial work was required from the CAA. This was because they believed an aircraft on a PTF could do aerial work for the purpose of demonstration and exhibition flying.

The test pilots' school stated that they thought the aircraft had a Certificate of Airworthiness and were not aware that the aircraft was operating on a PTF.

The CAA stated that they had not had any applications for a Yak-52 to do aerial work or to carry any additional persons while conducting a demonstration flight.

Footnote

[11] The terms 'demonstration' and 'exhibition' were not specifically defined in the ANO.
[12] G-YAKB's PTF states that the minimum flight crew is one pilot.

Yak-52 emergency procedures

The CAA stated that they do not approve a flight manual/pilot's notes for aircraft operating on a PTF. However, a checklist could be created from the information in a flight manual accepted by the CAA as appropriate for that aircraft and the relevant limitations/conditions to enable the safe operation of the aircraft would be stated on its PTF. The emergency procedures in the flight manual accepted by the CAA were comparable to the ones from the YAK-52 manufacturer's flight manual quoted below.

The commander provided the AAIB investigation with a checklist. He stated that there was not one in the aircraft as he had committed the aircraft's normal and emergency procedures to memory. When he flew in the front seat he described the checks he was performing to the rear seat occupant and when in the rear seat he talked the front seat occupant through the checks. The engine failure checklist read as follows:

> ***'ENGINE FAILURE***
>
> *Establish 172 KPH Glide*
>
> *Retract Landing Gear*
>
> *Check Mags, Fuel and Pump*
>
> *Turn Pump to left and pump fuel pressure to .1 to .2*
>
> *Attempt restart'*

The YAK-52 manufacturer's flight manual[13], published in 2002, had the following emergency checklists relevant to the symptoms reported by the commander:

> ***'5. IN-FLIGHT EMERGENCY CASES***
>
> ***5.1. PILOT'S ACTIONS IN CASE OF ENGINE SHUT DOWN DURING FLIGHT***
>
> *…*
>
> *5.1.3. If the engine stops during inverted flight:*
>
> - *perform a half-rolling and bring the airplane in normal flight:*
> - *set the gliding speed at 170-180 km/h:*
> - *bring the throttle lever at about one third of stroke:*
> - *bring the injection pump handle at 45º to the left and supply fuel until the fuel pressure at carburet[t]or intake is 0.*1-0.2 kgf/cm^2.
>
> *NOTE: To make the engine start easier, it is advisable to pump fuel in the engine cylinders* [right][14]*.*

Footnote

[13] The original flight manual was written in Russian. The manufacturer had translated it into English.

[14] Pumping fuel in the right position can assist engine start once the fuel pressure has been raised to 0.1 to 0.2 kgf/cm^2 by pumping in the left position.

> *5.1.4. As soon as the engine starts running again, bring the throttle lever in take-off condition [full power] for 1-2 seconds, then set the required flight condition.*
>
> *…*
>
> ***5.3. PILOT'S ACTIONS IN CASE OF FUEL PRESSURE DECREASE***
>
> *5.3.1. The fuel pressure decrease is signal*[l]*ed by:*
>
> - *discontinuous engine running accompanied by the deceleration of the engine speed, the reduction of the intake pressure and trepidations;*
> - *the decrease of the fuel pressure as read on the control instruments, below allowed limits.*
>
> *5.3.2. In case of fuel pressure decrease the pilot must;*
>
> - *report to the flight controller;*
> - *rotate the fuel pump lever 45º to the right* [left][15] *and start fuelling the fuel system, checking the pressure by reading the pressure gauges;*
> - *interrupt the mission and land on the home- or auxiliary aerodrome.*
>
> ***5.17. SPECIAL AIRPLANE FEATURES WHEN LANDING WITH DAMAGED ENGINE***
>
> *5.17.1. …In case of a forced landing on a rough or unknown ground, the landing will be performed with the undercarriage retracted.*
>
> *…*
>
> *5.17.4 In case of emergency landing and engine failure, the pilot must perform the following operations:*
>
> - set the instrumental airspeed to 160 km/h;
>
> *…*
>
> - *shut the fire cock* [fuel shutoff lever]*, switch off the magneto, the generator, and the ignition;*
> - *determine the height of flight…and calculate the available gliding distance so as to assess the possibility of landing on the aerodrome.*

Another flight manual, published by a UK Yak-52 maintenance organisation in 1995, additionally stated:

> *'Following an in-flight failure of the engine driven fuel pump the primer, set to CARB* [left]*, may be used as an emergency fuel pump to maintain fuel pressure and thus enable the aircraft to be flown to the nearest diversion airfield.'*

Footnote

[15] The manufacturer stated that this procedure, as published, is incorrect and the pump lever should be turned to the left.

Yak-52 glide performance

The YAK-52 manufacturer's flight manual stated that after an engine failure the aircraft should be flown at 160 km/hr [86 kt], with the landing gear and the flaps retracted. The gliding range is calculated by multiplying the height by seven (a glide ratio of 7:1) and equates to approximately 1.15 nm per 1,000 ft. To ensure minimum height loss, turns should be flown with 45º angle of bank. A 360° turn, at best glide speed and with 45º angle of bank, has a radius of 200 m, a rate of descent of 8 m/s [1,575 ft/min] and a height loss of 220 m [720 ft].

A forced landing on rough or unknown ground should be carried out with the landing gear retracted, to reduce the risk of tipping over.

The commander had previously flown in a PA-28, a side-by-side seat aircraft, and a Bellanca 8KCAB, a tandem seat aircraft, with the most recent flights in March 2016. Their glide ratios are about 10:1 and 12:1 respectively.

Aircraft information

General

The Yak-52 (Figure 6) is an all-metal, two-seat, tandem, single-engine low-wing monoplane, designed by the Yakovlev Design Bureau in Russia as a basic aerobatic training aircraft and manufactured in Romania by Aerostar S.A.. The type first flew in 1978 and about 1,900 were built. Production ceased in 2010.

The aircraft type never received civil or military type certification. A number of Yak-52's and their similar single-seat version Yak-50's were brought to the UK in the 1980's and 1990's and operated on the Russian or Lithuanian register. From 2002 the CAA required that all Yak's be registered in the UK and operated under a PTF. Each aircraft brought onto the register received an Airworthiness Approval Note (AAN) listing its limitations and maintenance requirements. As of January 2017, there were 40 Yak-52's and 20 Yak-50's on the UK register.

Figure 6

The accident aircraft G-YAKB

The Yak-52 is powered by a 360 hp nine-cylinder, single-row, air-cooled radial M-14P engine[16] driving a two-bladed, variable-pitch wooden propeller via an epicyclic reduction gear. Mounted on the rear of the engine are a pressure carburettor and an accessory gearbox. The latter drives a single stage supercharger, a compressor, dual magnetos, a fuel pump, an oil pump, a tachometer and a generator.

The fuel consumption during aerobatic flying is reportedly about 90 litres/hr, and about 10 to 12 litres/hr at idle power. According to the flight manual the maximum range fuel flow is 37.3 litres/hr at 57% engine rpm and 192 km/hr (104 kt).

The electrical system is 28V DC, supplied by two batteries and the engine-driven generator. This is primarily used to power the aircraft instruments, radio and intercom. The flaps, landing gear and engine starting are powered by a pneumatic system fed by two air-filled pressure vessels which, in turn, are supplied by the engine-driven compressor.

The flight controls are conventional, with a central stick controlling the ailerons with push-pull rods and the elevator with cables; while pedals control the cable-operated rudder. The elevator trim is operated with a trim wheel and cable.

YAK-52 cockpit instruments and controls

On the left side of the front cockpit is a yellow throttle lever, alongside a propeller speed control lever (Figure 7). In front of these levers is a black fuel shutoff lever (shown red in Figure 7). The fuel shutoff lever is pulled aft to shut off the fuel in an emergency, and normally remains in the full forward position (as shown) at the end of a flight. These three control levers are replicated on the left side of the rear cockpit and each is mechanically connected to its counterpart in the front cockpit, so that the front and rear levers move in unison. The landing gear lever is on the left side of the instrument panel and has three positions: UP, NEUTRAL and DOWN. There is a manually-selected sliding safety gate on the selector to prevent the gear being selected up inadvertently on the ground. To select the landing gear down, the gear lever is pushed in and moved from UP to DOWN and the safety gate is slid to the right. The rear cockpit landing gear lever is normally left in the central NEUTRAL position, which gives priority to the front lever. The pneumatically operated landing gear can take up to 15 seconds to move to the fully locked down position. The flap lever is located aft of the throttle lever and has two positions, FORWARD and AFT to select flaps up or full down. The rear cockpit flap lever in G-YAKB was gated to render it inoperable.

The levers to control the engine cowl flaps and the carburettor heat are on the right side of the front cockpit; they are not replicated in the rear cockpit. On the right side of the front instrument panel are the fuel gauge and the fuel primer handle (Figure 8). The fuel gauge uses small light bulbs to illuminate the fuel quantity in the left and right main tanks. The fuel primer handle has three positions: LEFT, CENTRE and RIGHT. The function of this handle is described in the fuel system section of the report.

Footnote

[16] The majority of M-14P engines, including the one on G-YAKB, were manufactured by the Voronezh Mechanical Plant (VMP).

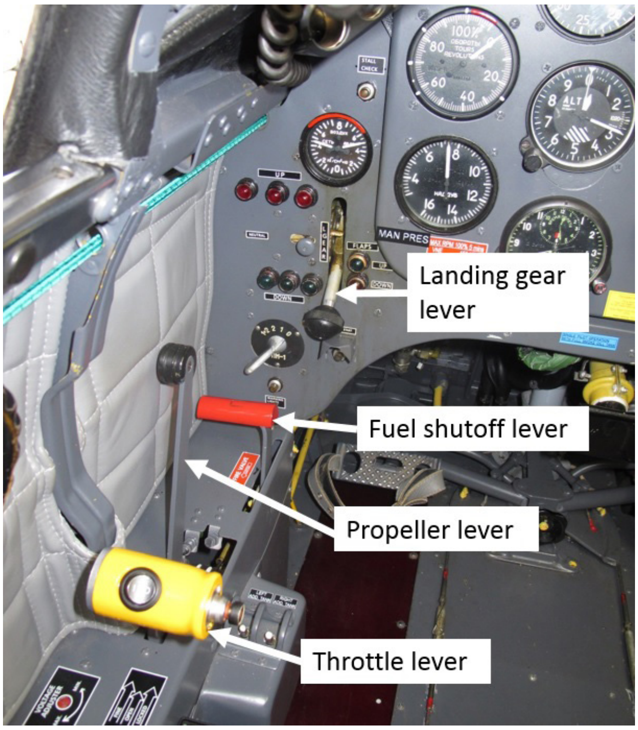

Figure 7

Front cockpit controls (left side) from a different Yak-52.
Fuel shutoff lever shown in the forward 'fuel on' position.
On G-YAKB the fuel shutoff lever handle was black

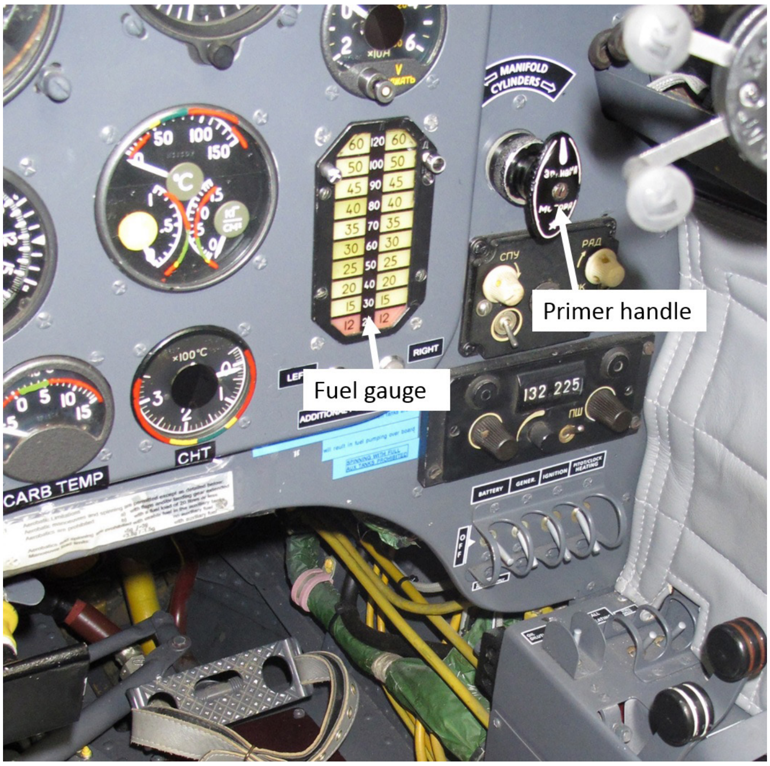

Figure 8

Front cockpit controls (right side) from a different Yak-52

The rear cockpit altimeter in G-YAKB was placarded inoperative, as it had failed an accuracy test. There was no manifold pressure gauge in the rear cockpit, but there was one in the front. The front and rear heading indicators had been unserviceable for some time, although both wet compasses[17], on top of the instrument panel, were reportedly serviceable. The commander and some students who flew earlier in the week reported that the front and rear engine rpm gauges were not functioning correctly; they would either indicate zero, run backwards or sometimes work correctly. This did not have any effect on engine performance, but these gauges were needed for proper engine management. Students also noticed that the rear cockpit attitude indicator was not displaying a steady, usable horizon.

The minimum equipment requirements for a VFR aircraft, at the time of the accident, were: an airspeed indicator, an altimeter and a compass, of which a wet compass would have been appropriate.

YAK-52 fuel system description

The fuel system includes two wing tanks, each of 61 litres capacity, which gravity-feed a 5.5 litre collector tank in the lower centre section of the aircraft (Figure 9). The engine-driven fuel pump draws its fuel supply from the collector tank which provides a short-term supply of fuel for inverted flight (up to 2 minutes is permitted). There is no left/right fuel tank selector, so both tanks feed the collector tank continuously via non-return (‘flapper’) valves. The first pair of non-return valves prevent fuel from passing from one tank to the other. The third non-return valve prevents fuel from flowing from the collector tank back to the main tanks. A rubber flop-tube inside the collector tank is connected to the fuel outlet. The flop-tube is weighted at its end so that it rests at the bottom of the tank during normal flight and rests at the top of the tank during inverted or negative-g flight; this ensures that the outlet can always draw the fuel in the tank.

From the collector tank the fuel passes through another non-return valve, the fuel shutoff valve, a coarse fuel filter, the engine-driven fuel pump, a compensation tank, and a fine fuel filter, before entering the pressure carburettor. The compensation tank provides a pressurised fuel reserve because the pressure carburettor does not have an integral tank. Excess fuel from the compensation tank is returned to the collector tank via a restrictor. Fuel pressure is sensed between the fine filter and the carburettor and is displayed on both front and rear cockpit gauges.

The fuel shutoff valve is normally only used in the event of a fire or forced landing. Fuel downstream of the valve is sufficient to run the engine for about 1 minute at idle. There is no electric fuel boost pump as seen on many low-wing certified aircraft, so if the engine-driven fuel pump fails, the engine will suffer a complete loss of power. Later model Yak-52W and TW variants are fitted with an electric fuel boost pump.

A manual primer handle, installed in the front cockpit, is used to start the engine. When turned to the left ‘System’ position (labelled ‘Manifold’ in Figure 8) and when pulled out and

Footnote

[17] Wet compasses requires a steady flight path in order to be read accurately.

pushed in, the plunger in the handle draws fuel from a position upstream of the collector tank, as shown in Figure 9, and pumps it into a position between the collector tank and fuel shutoff valve. This primes the fuel lines, fuel pump and carburettor for engine start. When the primer handle is turned to the right 'Cylinder' position and pumped, fuel is drawn from the same location but is pumped into the supercharger compressor. This provides some vapourised fuel ready to be drawn into the cylinders as soon as the engine is turned over.

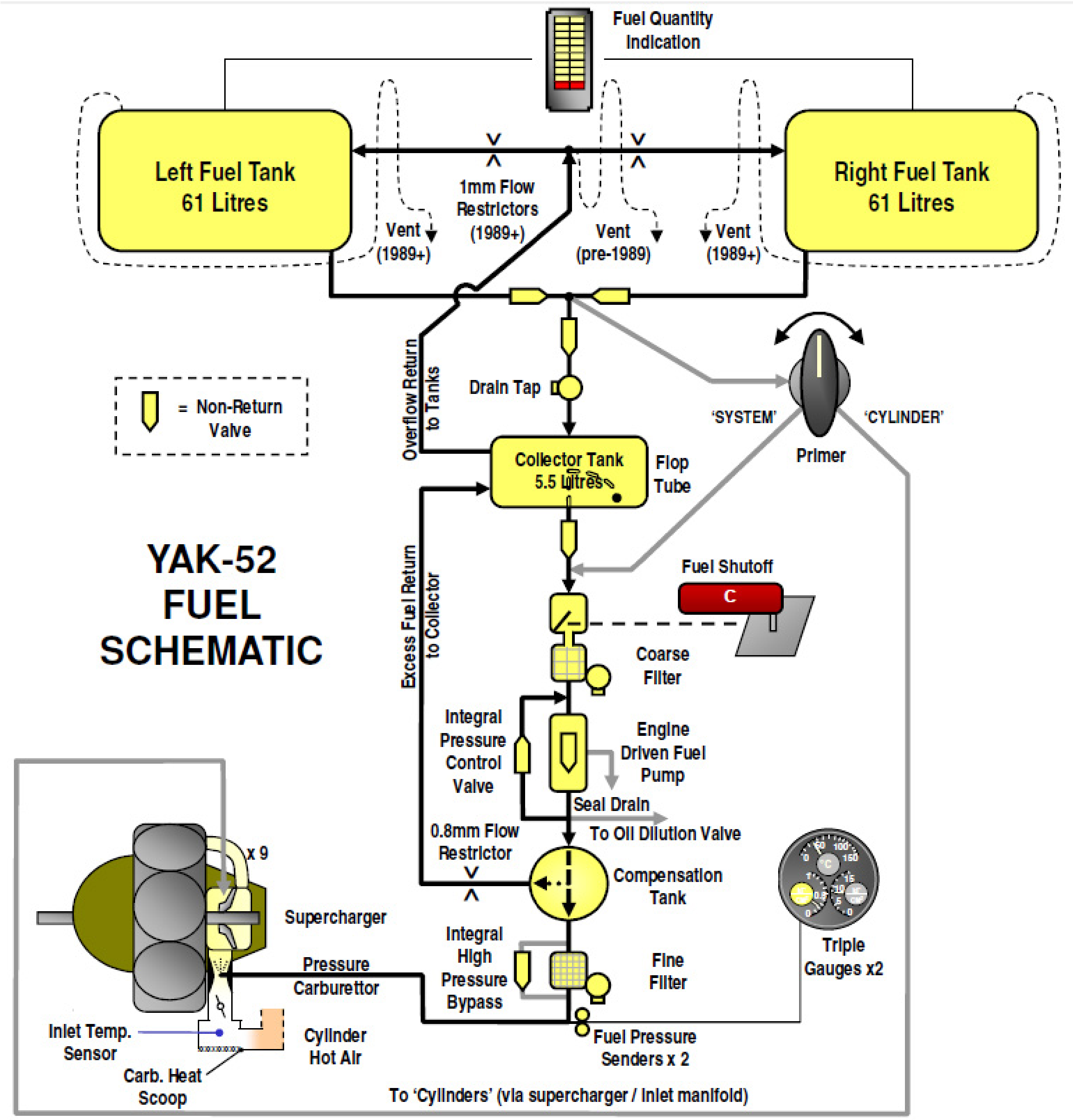

Figure 9

Yak-52 fuel system diagram (© Robert A. Rowe)

According to an unofficial flight manual and from anecdotal evidence, the primer handle can be used in the left 'System' position to maintain some engine power after a fuel pump failure. However, the aircraft manufacturer does not specify a rate at which the primer handle needs to be pumped to maintain level flight.

If the primer handle is pumped in the right 'Cylinder' position following a fuel-related loss of power, then unmetered fuel would be pumped into the engine, possibly causing brief bursts of power but not sustained running.

According to a Yak expert, the engine-driven fuel pump is very sensitive to ingested air. The pump will not easily suck air, so if sufficient air is introduced into the fuel upstream of the fuel pump the fuel pump may not be able to draw any fuel.

The pressure carburettor requires fuel to be delivered under pressure because it does not have a float chamber. The lack of a float chamber means that it will work while inverted, but the disadvantage of this design is that it must be constantly fed with pressurised fuel. Any air or vapour in the fuel in the carburettor can result in the engine losing power almost instantly. This is why significant priming is important for engine start.

Maintenance history

The aircraft was being maintained in accordance with the CAA's Light Aircraft Maintenance Schedule (LAMS/A/1999/Issue 2).

At the time of the accident the airframe had logged 500 hours and the engine had logged 516[18] hours. The propeller was overhauled in 2013 and had logged 48 hours.

In 2013 the aircraft underwent a CAA-approved lifetime extension inspection which extended the airframe's original 20-year life by 10 years. During this inspection an automotive spark plug conversion, in accordance with a CAA modification approval, was carried out. All the flexible fuel and oil hoses, and the carburettor diaphragm were replaced in December 2014. The last annual inspection was completed in February 2016 at 479 airframe hours.

According to the aircraft's AAN, the engine was due its first overhaul at 750 hours, and subsequent overhauls every 500 hours, with a maximum life of 2,250 hours. The engine on G-YAKB had logged 516 hours, so it was not yet due its first overhaul. The records indicated that the engine had been fitted to G-YAKB since build, so had been in service for 24 years without an overhaul. The original Russian engine logbook specified a first engine overhaul after 750 hours or 6 years[19]. There was no calendar overhaul life defined in the AAN. However, the CAA stated that their engine overhaul life principle was for operators to use the manufacturer's specified overhaul life and justify any changes. CAA CAP 747 '*Mandatory Requirements for Airworthiness*', Generic Requirement No. 24 '*Light Aircraft Engine Overhaul Periods*', allows engines in aircraft only used for private flying to continue in service indefinitely, subject to certain conditions. However, for aircraft being used for aerial work the calendar overhaul life limits apply unless an alternative life can

Footnote

[18] Prior to 2002 the aircraft was registered in Lithuania, where a percentage of the engine ground running time was included in the engine total time.

[19] According to the Russian Air Accident Investigation Commission, at the first 6-year overhaul the overhaul organisation decides the next calendar overhaul period, which would be 6 years or less, and this would be entered in the logbook. This applies to engines manufactured by VMP.

be justified[20]. Since no Yak-52 operator has yet approached the CAA for permission to conduct aerial work, the CAA could not state what alternative life, if any, would be approved.

Aircraft examination

Airframe examination

The airframe had suffered significant damage to its nose; from the front instrument panel forwards it was almost completely detached from the rest of the airframe. The left wing leading edge and wingtip had suffered crushing damage. The right flap was almost up and the left flap was down and angled forwards, although this was explained by the rod connecting the left flap to its actuator having failed. The front flap lever was in the up position and the lack of damage to the flap trailing edges indicated that the flaps were up at impact. The front landing gear lever was in the DOWN position with the safety gate closed, while the aft landing gear lever was in the NEUTRAL position. The nose landing gear leg and its actuator had suffered significant damage and disruption, indicating that it had probably been down or partially down at impact. The right main landing gear leg was up but not locked, while the left main landing gear leg was up and locked.

The flight controls were examined and there were no disconnections apart from breaks associated with impact damage. The elevator trim tab was in a near neutral position.

The engine controls were examined and there were no disconnections apart from breaks associated with impact damage. The throttle and propeller levers could have easily moved in the impact sequence, so their positions were not reliable pre-impact positions. The front fuel shutoff lever was in the aft closed position which corresponded to the position of the shutoff valve, but there was significant disruption to the control rods to the extent that the interconnecting aft fuel shutoff lever was in the open position; therefore a reliable pre-impact position could not be determined. The air intake flap had been torn off during the impact sequence which indicated that the flap was probably open and, therefore, that the carburettor heat was set to cold at impact. The front cockpit magneto switch was damaged and the selector was 180° out from any normally selectable position, while the aft cockpit magneto switch was set to '1+2' (both). The front cockpit switch panel housing the generator and battery switches had suffered a significant impact which meant that the switch positions were not reliable pre-impact positions.

Instrument examinations

The bulbs from the rear cockpit Central Warning Panel (CWP) were examined. These included bulbs which illuminate to indicate that the left and right fuel tank levels are less than 12 litres in each side, that the generator is not producing sufficient output, that the

Footnote

[20] CAA CAP 747 Generic Requirement No. 24 states that calendar limits must be observed if the aircraft is used for the purposes of Public Transport or Aerial Work. Aerial work means any purpose, other than commercial air transport or public transport, for which an aircraft is flown if valuable consideration is given or promised for the flight or the purpose of the flight. In August 2016 the term 'aerial work' was replaced with 'commercial operation' when The Air Navigation Order 2016 was introduced.

master switch is turned on, and a stall warning indication which illuminates close to the stall. The bulbs were examined under the microscope to look for indications of filament stretch. A stretched filament indicates that it was probably hot at impact and, therefore, that the light was on[21]. Both the bulbs for the master switch caption and the bulbs for the generator caption were stretched, indicating that the master switch was probably on at impact and that the generator was probably generating below normal output. According to a Yak expert, if an engine is windmilling following a loss of power, then the generator output would be sufficient to prevent this light from illuminating if the aircraft is at best glide speed. The cut-off airspeed is not known, but it is possible that near stalling speed the generator caption might illuminate if the engine had lost power. None of the remaining bulbs had stretched, indicating that the fuel level in each tank was above 12 litres and that the stall warning was probably not illuminated at the moment of impact.

The light bulbs inside the fuel gauge (Figure 8) were also examined and three of the bulbs were found to be stretched. These were for the left tank quantities 40 and 45, and for the right tank quantity 40. During transition from one indicated level to the next, the two quantities can be flickering on and off. This indicated that the left fuel tank quantity was probably between 40 and 45 litres and the right fuel tank quantity was probably about 40 litres.

Powerplant examination

One of the two propeller blades had separated at its root and broken into pieces at impact. The tip of this blade had chordwise scratches consistent with rotation. The blade which remained attached was relatively undamaged, with light chordwise scratching on its forward face near the root, but none at the tip. This evidence indicated that the propeller was rotating at impact but had stopped almost immediately, meaning that the engine was probably producing little, or no power.

A full strip examination of the engine was carried out at an approved maintenance facility by an engineer with experience of M-14P engines. Cylinders 3 and 4 (in the lower left corner) had detached, but the damage was consistent with bending failures associated with ground impact in that location. No mechanical damage was found that would explain a loss of power. Both magnetos had suffered impact damage but when tested with their respective ignition leads, the magnetos produced good steady sparks at low and high rpm. The spark plugs were in satisfactory condition.

The carburettor was too damaged to test, but a strip examination did not reveal any anomalies or defects.

The drive from the accessory gearbox to the fuel pump was checked and was intact. The fuel pump had been knocked off its mounting plate during the impact which had also caused its fuel outlet connection to break. The pump was mounted in a fuel pump test rig and at low rpm there was no fuel flow. When the rpm was increased to 1,000 rpm, the

Footnote

21 Hot bulb filaments are more ductile than cold filaments which makes them more likely to stretch than break during a high-g impact. Cold filaments are brittle and are likely to break without any stretch.

flow started. When the rpm was subsequently reduced to 450 rpm the flow remained. The test engineer explained that the lack of initial flow was due to air in the system. The higher rpm was required to suck the air through and prime the fuel lines. At 2,200 rpm and a specified back pressure of 1.4 psi, the fuel flow exceeded the minimum requirement of 175 litres/hour by 80 litres/hour.

Fuel system examination

Both main fuel tanks were empty apart from a small trickle of fuel, while the collector tank contained 1.8 litres of fuel. Soil samples beneath the aircraft revealed the presence of fuel, although an accurate quantity could not be determined. There were sufficient impact-related breaks in the fuel lines to explain the loss of fuel from the main tanks. The fuel in the collector tank was tested and conformed to the properties of AVGAS 100LL, with no evidence of contamination.

The non-return valves and attached fuel pipe work were removed and tested with fuel. The valves operated normally with no sticking. The valves were additionally strip examined and there was no evidence of sticking. The flop-tube inside the collector tank was examined and it was free to pivot between top and bottom. The collector tank was partially filled with fuel and fuel flowed to the outlet when inverted and then righted.

The coarse and fine fuel filters were not blocked. The fuel hose at the outlet of the coarse filter was loose; it had backed off about 90° from a hand-tight position. The fitting had been wire-locked to the bolt securing the filter bowl to the firewall, but this attachment had failed in the impact so the end of the wire-locking had come free. When the end of the wire-locking was positioned in its likely pre-impact position, there was sufficient slack for the fitting to back off to the as found position, although it's possible that the wire-locking had stretched when the attachment failed. The filter bowl was filled with fuel but no fuel leaked out of the loose fitting. An additional test was carried out to see if air could be entrained through the loose fitting. A clear plastic hose was attached to the filter bowl outlet and a hand pump, while another hose was connected to the filter bowl inlet and a fuel tank. During pumping some air bubbles were seen in the outlet hose, and the amount of bubbles reduced when the outlet fitting was hand-tightened.

The spherical-shaped compensation tank had been flattened during the impact so could not be tested, but its fittings were secure.

The fuel primer handle had separated from its cockpit mounting during the impact and its three connecting fuel pipes had failed. The handle had also broken off and its position was half-way between left and neutral. When the primer is in the full left or full right position the handle needs to be pushed inwards before it can be rotated; however, when in the central position it can be rotated left or right without being pushed in which means that it can be knocked left or right from neutral. There is a knurled collar at the base of the primer handle which can be tightened to reduce leaks but also increases the resistance to pumping. The primer was tested by pumping 10 strokes in the left and right positions with the collar in the as-found position. This resulted in an average flow rates per stroke of 8.6 ml in the left position and 7.2 ml in the right position. With the collar fully tightened the flow rate increased to 9.2 ml and 9.3 ml per stroke in the left and right positions respectively.

Tests were carried out with the collar in the as-found position to see if the flow rate reduced when the pump was actuated at a high rate. When the pump was actuated in the left position 13 times in 10 seconds (1.3 strokes per second) the average flow rate was 8.2 ml per stroke. This would result in a flow rate of 38.4 litres/hour, which would be sufficient to maintain level flight given that the maximum range fuel flow[22] is 37.3 litres/hr.

Seat harness examinations

The front and rear seats were fitted with 5-point harnesses. The straps were secured using a pin and cone fitting (Figure 10). The strap ends with holes are slotted over the cone and then held together by a butterfly pin. This pin is pulled out sideways to release the straps and a short lanyard tethers the pin to the right lap strap. The front and rear seat lap straps were made of a tan linen outer layer and a nylon inner layer, which was the type of strap fitted at original manufacture. The front and rear seat crotch straps and upper portions of the shoulder straps were made of a blue nylon material which was similar to the original type used, but could not be confirmed as such. The lower portions of shoulder straps were made of the same tan linen/nylon material as the lap straps. The blue nylon straps were about 1.6 mm thick but doubled up in some areas. The tan linen/nylon straps were about 4 mm thick and consisted of 2 mm thick layers stitched together.

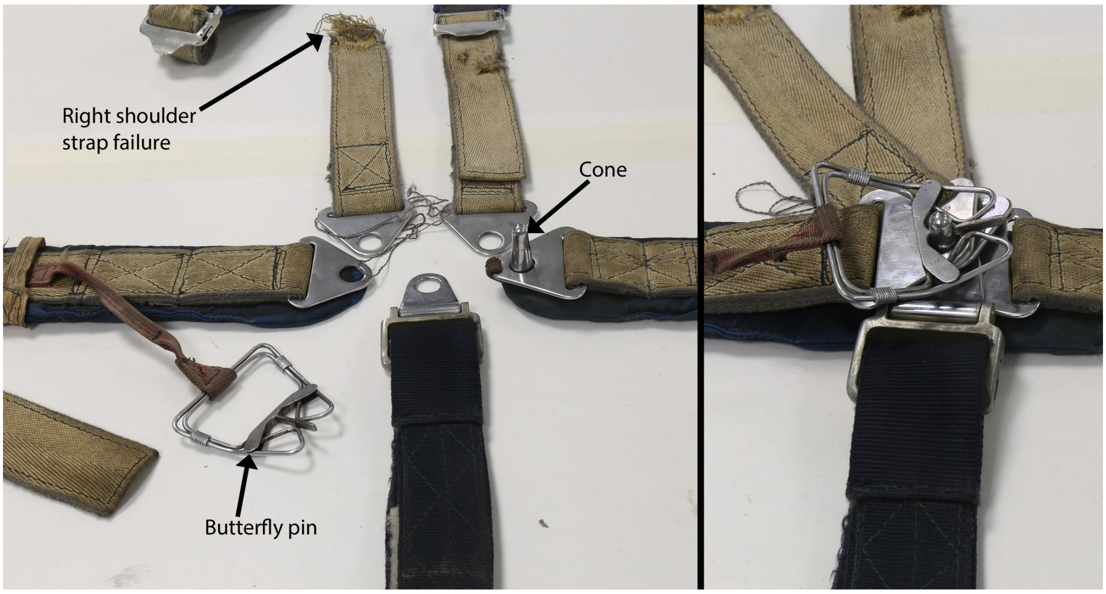

Figure 10

Front seat 5-point harness as found (left); all straps secured (right)

Footnote

22 The maximum range fuel flow is the fuel flow that will maximise how far the aircraft can fly. The maximum endurance fuel flow is the minimum fuel flow required to maintain level flight for as long as possible, which will be slightly less than the maximum range fuel flow quoted here. The manufacturer does not quote the maximum endurance fuel flow.

The front seat right lower shoulder strap had failed in overload at the adjustable buckle (Figure 10) and the crotch strap had failed at its lower fuselage fitting. This lower fitting failure was probably caused by distortion of the floor and seat structure which resulted in the seat pan moving forwards against the crotch strap. The front seat lap straps had not failed but the butterfly pin had come out, so the straps were no longer connected. If the butterfly pin had not been inserted at the time of impact it is unlikely that the shoulder strap or crotch strap fitting would have failed. It appeared most likely that the pin came out during the impact sequence which allowed the FSP to be thrown from his seat. There were no witness marks on the pin or on its tether to help explain how it came out.

The rear seat upper shoulder straps had both failed in overload above the adjustable buckles (Figure 11), and the rear seat left lap strap had failed at the adjustable buckle (Figure 12). The butterfly pin was also out, but one witness who attended the scene believes he removed it to help the commander out of his seat.

Figure 11

Rear seat shoulder harnesses (both failed at upper strap)

Figure 12

Rear seat left lap strap (failed at adjustable buckle)

The blue shoulder straps were significantly sun faded on their outer exposed surfaces; their inner surfaces were a much darker blue. The tan straps also appeared to be discoloured compared to what their original appearance probably would have been. Samples of the straps were subjected to characterisation using Attenuated Total Reflectance Fourier Transform Infrared (ATR-FIR) spectroscopy to determine if any chemical degradation had occurred. Minor differences in the spectra were observed when comparing some exposed surfaces to unexposed surfaces, suggesting some minor degradation had occurred, but this could not be quantified in terms of loss of strength.

Tensile strength tests were carried out on the front seat left and right lap straps. The left strap failed at 570 kgf, while the right strap failed at 460 kgf. Some strength reduction may have occurred during the impact but this could not be estimated. The fact that the lap straps had come undone in the impact would have reduced the loads they had experienced.

The shoulder straps were too short to be tested in a tensile test machine. The aircraft manufacturer could not provide a definitive strength figure for the original straps at manufacture and this type of linen/nylon strap is no longer made. One document provided related to an antiseptic and anti-mould treatment of the straps. It listed a strength of 450 kgf for a linen material that was 2 mm thick. It did not mention the nylon material or provide a strength figure for a stitched double layer. If this was the same linen material used on G-YAKB then it could possibly have had an original strength of 900 kgf or possibly more with the nylon.

A replacement strap was obtained from a company in Lithuania which maintains and overhauls Yak-52 aircraft. This new replacement strap was made of polyester and had a minimum break strength of 2,650 kgf, which is consistent with military strength requirements[23].

The civilian strength requirements are specified in terms of deceleration rate using an assumed pilot mass with static and dynamic tests, instead of tensile strength.

Survivability

The RAFCAM reviewed and reported on the FSP's post-mortem report and a summary of the injuries sustained by the commander.

The FSP wore a headset[24] provided by the commander, and the commander wore a Campbell Aero Classics hard shell flying helmet with integrated goggles. The RAFCAM report stated that had the FSP been wearing a protective helmet, it is possible that the protection afforded could have reduced the severity of his head injuries. The presence of helmet visors, if worn in the locked down position, could have provided some added protection and may have lessened the severity of the facial injuries. Similarly, a helmet's shell could have mitigated the forces causing the head injuries. However, it was difficult to determine if a helmet and visor combination could have reduced the injuries to the extent that the accident might have been survivable.

Footnote

23 The Aircraft Crash Survival Design Guide (AD-A218 437, Vol 4) and Military Specification Seat System: Crash-Resistant, Non-Ejection, Aircrew, General Specification For (MIL-S-58095A) indicate that the minimum tensile breaking strength of webbing harnesses should be 2,721kg.

24 A hard shell helmet was available to the students earlier in the week, but as a result of intercom difficulties it was replaced with a headset.

The commander's injuries included fractures to his facial bones, bilateral fractures to lower limbs, and fractures to his pelvis, ribs and palm of his right hand. His left eye was also seriously injured.

The FSP had similar hand injuries, but his were coupled with upper limb injuries. The fact that the commander's hand injuries were in isolation of upper limb fractures could indicate that he had his hand on the control column at the time of the impact. However, such injuries can be non-specific and so this evidence is inconclusive.

According to the RAFCAM report, it was likely that the commander's facial fractures resulted from impact with the instrument panel in the rear cockpit and that his forward flail would have been compounded by the failure of his shoulder harness straps.

The RAFCAM report also stated that it was likely that the failure of the front-seat webbing of the shoulder harness and the detachment of the anchor point of the negative-g strap, coupled with the inadvertent release of the harness's locking mechanism, would have influenced the severity of the FSP's head and face injuries. However, they could not determine conclusively if the severity of the FSP's injuries would have been lessened had the harness straps remained undamaged and the locking mechanism intact.

The type of helmet worn by the commander had been previously tested by RAFCAM. It was determined that this helmet had considerably less impact energy attenuation than the standard Mk 10 and Mk 4 series of helmets typically worn by military pilots.

Other information

Previous Yak-52 loss of power accidents and incidents

The AAIB has published previous reports on 45 Yak-52 accidents. Of these, six were fatal, and none of the fatal accidents involved a loss of power or a forced landing. Five of the 39 non-fatal accidents involved a loss of power and a forced landing. Two cases involved spark plug failures and one involved an accessory driveshaft failure. In the remaining two cases no cause of the loss of power was found. Loss of power events which do not result in an accident (ie no serious injury or no damage sustained during the forced landing) are not reported on; including those experienced by the commander of G-YAKB.

An experienced Yak pilot informed the AAIB of a loss of power he experienced in a Yak-52 in October 2016. It occurred at the top of a stall turn when the engine suddenly lost all power without prior warning. The pilot recovered from the dive and set best glide speed. The fuel pressure was normal and the propeller was windmilling at an engine rpm of about 60%. The throttle was free to move fore and aft, so he ruled out carburettor ice[25]. Because the fuel pressure was normal and stable, he asked the FSP to pump the primer with it set to the right 'cylinders' position. This did not have an immediate effect, but after some time the engine started firing and eventually began running normally. The loss of power lasted about 60 to 75 seconds and the aircraft lost about 2,000 ft of height. A

Footnote

[25] Carburettor ice is known to cause the throttle to stick with this carburettor type.

normal landing was carried out. A detailed engine and fuel system examination by an engineer did not reveal any faults that would have caused the loss of power. Whilst this loss of power remains unexplained, it provided evidence that a windmilling propeller can turn the fuel pump sufficiently fast to generate normal fuel pressure.

Operating piston engines for long periods without overhaul

In July 2009, a P56 Provost T1 (G-AWVF) with an Alvis Leonides radial piston engine suffered a mechanical failure which led to an in-flight engine fire and a fatal accident[26]. The failure was caused by a fatigue failure of a piston gudgeon pin. Corrosion pits on the inner surface of the pin were probably a contributory factor. This engine had not been overhauled in 45 years. This resulted in AAIB Safety Recommendation 2010-029, which recommended that the CAA:

> *'consider implementing calendar time limits between overhauls for Alvis Leonides series engines, and other historic aircraft engines that do not have manufacturer-recommended calendar limits.'*

The CAA responded to this recommendation by publishing Leaflet 70-80 '*Guidance Material for Ageing Engine Continuing Airworthiness*' in CAP 562 '*Civil Aircraft Airworthiness Information and Procedures*' on 31 October 2012. This leaflet states that in the absence of a manufacturer's published calendar life the engine is required to be overhauled after 20 years unless a hazard analysis for continued operation is carried out. However Leaflet 70-80 only applies to radial piston engines with power in excess of 400 hp, and therefore does not apply to the Yak-52's M-14P engine.

Maintenance requirements for seat harnesses

The Yak-52 Scheduled Servicing Manual[27] states to do the following inspection on the front and rear cockpit seat harnesses at every 50-hour and every 100-hour/Annual check: *'Inspect the belt system, check belt fastening and belts condition, lock operation'.*

The CAA's Light Aircraft Maintenance Schedule (LAMS/A/1999/Issue 2) states to inspect '*Seats, belts/harnesses, attachment, locking and release*' at 50 hours or 6 months, whichever occurs first. According to the CAA, they would expect this check on the belts to include '*wear/fraying, loose stitching, security of attachment and correct operation'*. There is no requirement to check for sun-fading or to track the age of the harnesses.

The aircraft manufacturer stated that the aircraft life was 20 years and therefore they considered the life of the seat harnesses also to be 20 years. The CAA's approved 20-year lifetime extension inspection was focussed on structural inspections and did not refer to seat harnesses.

Footnote

26 AAIB Bulletin 10/2010.
27 RGA/Yak52/Maint – 1988 R1 – January 2003

Analysis

General

The aircraft's engine failed without warning after a period of aerobatics, which included some inverted flight. Despite the FSP's attempts to restart the engine and maintain some power by pumping the primer, this was unsuccessful and a decision was taken to carry out a forced landing.

Operational aspects

The FSP did not attend the mandatory 90-minute Technical and Safety Briefing at the beginning of the QE week. His flight was brought forward with the pilots being observed in discussion for about 15 minutes before walking to the hangar where they appeared rushed. This was a short amount of time for the commander to brief the FSP on the aircraft's cockpit, delegation of duties and emergency procedures. This might have been significant, as some of the engine controls were only available in the front cockpit.

An aircraft operating on a PTF was not required to have a checklist and there was not one in the aircraft. The commander stated that he committed the aircraft's normal and emergency procedures to memory. In the absence of a thorough emergency brief the FSP was unlikely to have been able to proficiently assist with the fault diagnosis or any emergency drills. This would have been made more difficult with no checklist available.

Response to loss of engine power

The manufacturer's '*…Engine Shut Down During Flight*' checklist states: '*bring the throttle lever at about one third of stroke*' before pumping the primer handle in the left position and subsequently states: '*As soon as the engine starts running again, bring the throttle lever in take-off condition* [full power] *for 1-2 seconds*'. The '*engine failure'* checklist provided by the commander did not state anything with regards to throttle movement. The commander believed that, having exercised the throttle following the loss of power, he returned it to about 70% rpm. This was not in accordance with the manufacturer's checklist and may have been a factor that prevented the engine from restarting.

The attempted forced landing

The aircraft was at about 2,650 ft agl when the FSP transmitted "…PROBABLY GOING TO BE EH PFL ING [PRACTICE FORCED LANDING] TO A FIELD…" at 0932:06 hrs. The radar data shows that the aircraft continued on a steady heading to the east; during this time the pilots were primarily focussed on attempting to restart the engine with the expectation that they might be able to return to BD. The evidence shows that the commander committed to conducting a forced landing at 0933:29 hrs, at which time the aircraft was approximately 1,100 ft agl and travelling downwind. There were a number of suitable fields available for a forced landing into-wind and, given the commander's previous experience of forced landings in a Yak-52, a successful outcome should have been possible.

The evidence shows that, after the final radar point, the aircraft was initially flown in a westerly direction (into-wind), but this did not culminate in an into-wind landing. The position of the aircraft wreckage in the immediate vicinity of the strip and the commander's limited recollection point towards a late decision having been made to land on the strip. The fact that the landing gear was in transit is supporting evidence for this. It could not be determined whether the aircraft was flown to the north or the south of the strip. The commander's decision to land on the strip may have been influenced by having previously flown three successful forced landings, with the landing gear down, onto strips or runways.

There was about 1 minute, based on the average descent rate of 1,150 fpm, available from the time of the FSP transmitting that they were performing a forced landing into a field, to the aircraft reaching the ground. This was a short period of time to see the strip, commit to it and adjust the flight path to correctly align the aircraft with it. If the pilots had pursued the original plan to land in a field, it would have been less important to align the aircraft on a prescribed track, but more important to land into-wind. Given that the aircraft approached the strip downwind, it is likely that either the pilots' workload was too high for them to consider the wind direction, or they had incorrectly recalled it. The unserviceable heading indicator may have led to the pilot losing some degree of situational awareness, which may have contributed to the aircraft landing downwind.

A compounding factor was the commander being seated in the rear cockpit, which would have restricted his forward visibility, making it more difficult to manoeuvre the aircraft accurately at low level during the final approach to the strip. It is possible that the commander handed control to the FSP in the latter stages of the approach, but there was no definitive evidence as to who was at the controls immediately prior to the accident.

Cause of impact

The aircraft hit the ground in a steep left bank at the southern edge of the farm strip. Based on the damage and the distance travelled before coming to rest the aircraft was at low speed. The evidence from the CWP bulbs indicated that the generator light was probably on, which can occur at low speed, close to the stall. It is possible that the aircraft stalled prior to impact causing the left wing to drop, but it is equally possible that the aircraft was being manoeuvred at low speed to reach the strip with a deliberate left aileron control input in the last few seconds. The evidence from the landing gear indicated that it was probably in transit, which means that the landing gear was probably selected down using the front cockpit lever less than 15 seconds before impact.

Loss of power

The engine had suffered a complete loss of power but reportedly produced brief periods of power when the primer was pumped in the left position. The loss of power was reportedly accompanied by a loss of fuel pressure and pumping the primer in the left position caused the fuel pressure to increase. These symptoms are consistent with a fuel pump failure, but the fuel pump operated normally during a bench test and the fuel pump drive was intact. There were no disconnections in the fuel system, apart from breaks associated with impact forces. The non-return valves were tested with fuel and inspected; there was no evidence of the valves sticking that might have caused a loss of fuel pressure. All the filters in the fuel system were clear and no blockages in the fuel system were found.

The evidence from bulb filament analysis indicates that about 83 litres of fuel remained in the main tanks at the moment of impact, which is consistent with the expected fuel amount based on fuel burn estimates with full tanks on departure. The absence of fuel in the main tanks at the accident site can be explained by the breaks in the fuel lines associated with impact. The collector tank retained 1.8 litres of fuel which was tested and found to be normal for AVGAS.

A possible cause for the loss of power was that air had entered the fuel system. According to an experienced Yak engineer, the fuel pump will stop pumping fuel if sufficient air enters it. The outlet fitting of the fuel filter bowl was found to be loose and tests revealed that some air could be entrained, but it was not a significant amount. However, if sufficient air had entered the fuel system by this method, then the symptoms reported by the pilot could be explained. The fuel pressure indication would drop to zero and pumping the primer in the left position would cause the fuel pressure to momentarily increase, because the primer pump would be pushing fuel through the coarse filter to the fuel pump, which would not cause air to be entrained. It is the sucking action of the fuel pump that could have caused air to be entrained through a loose connection.

Carburettor icing was considered as a possible cause of the loss of power, but carburettor icing usually causes a gradual loss of power and rough running, neither of which were reported. Carburettor icing is also known to cause the throttle butterfly valve to freeze on the Yak-52, resulting in the throttle lever freezing; however, the pilot recalled exercising the throttle. Carburettor icing could explain a loss of power, but would not cause a loss of indicated fuel pressure.

Water in the fuel was another possibility considered. Water in the fuel can cause a sudden loss of power, but it normally occurs shortly after takeoff. The aircraft had been flown the day before and was in a hangar overnight, so the chance of water having formed in the tanks by condensation was low. In addition, water in the fuel would not cause a loss of indicated fuel pressure.

The manual pumping of the primer was reportedly at a rate of one stroke every 3 to 4 seconds, which produced brief bursts of power. The fuel primer tests revealed that such a stroke rate would not have produced sufficient power for level flight. A stroke rate of about 1.3 strokes per second would have been necessary to maintain level flight.

The cause of the loss of power could not be determined, but the reported symptoms indicated that the problem was related to the fuel system. There have been other cases of loss of engine power on Yak-52 aircraft that could not be explained.

The Yak-52 aircraft and its M-14P engine have not been certified to any international standard and so the aircraft is operated on a PTF, which potentially carries a higher risk compared to an aircraft operating on a Certificate of Airworthiness.

Survivability

RAFCAM reported that, had the FSP been wearing a protective helmet, it is possible that the protection afforded could have reduced the severity of his head injuries. However, it was difficult to determine if a helmet and visor combination could have mitigated the injuries to the extent that the accident might have been survivable for the FSP.

Seat harness condition

The seat harness lap straps were probably original and so would have been in service for 24 years, 4 years longer than that permitted by the aircraft manufacturer. When the CAA granted a 20-year lifetime extension, seat harnesses were not among the items that required replacement. The aircraft manufacturer could not provide a definitive strength figure for the original straps at manufacture, but they provided some evidence to indicate that the strap might have had an original strength in excess of 900 kgf. The right front seat lap strap had failed at 460 kgf, so it was possible that about 50% of its strength had been lost due to ageing. There is no requirement in LAMS to check for signs of ageing or to track the age of seat belts and harnesses. Therefore, it is recommended that:

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The Civil Aviation Authority should review the maintenance requirements for seat belts and harnesses, and, if necessary, revise the maintenance requirements to ensure that seat belts and harnesses remain in a condition with an acceptable residual strength.

Engine overhaul period

The engine had not been overhauled in 24 years. This was permitted by the CAA as long as the aircraft was not used for aerial work. If the operator had requested using G-YAKB for aerial work it is not clear what calendar limits, if any, the CAA would have imposed as a condition. Although there is no evidence that the lack of engine overhaul contributed to the loss of power, operating engines without calendar limits can cause problems as was the case in the accident to the P56 Provost T1 (G-AWVF). As a result of that accident the CAA now applies a 20-year calendar limit, unless a hazard analysis can demonstrate otherwise (Leaflet 70-80); however, it only applies to engines with more than 400 hp.

The CAA have stated that they are conducting a review of engine maintenance to determine if Leaflet 70-80 should be extended to all piston engines and whether any Alternative Means (Methods) of Compliance arising from Leaflet 70-80 should be made mandatory by means of a Mandatory Permit Directive (MPD). This will also include a review of Generic Requirement No. 24 in CAP 747.

Permit to Fly

G-YAKB was operating on a PTF. The ANO allowed PTF aircraft to do aerial work without CAA permission, by way of a demonstration flight. However, this could only be done with the minimum flight crew, which would be one in a Yak-52. If additional persons were to be carried, then CAA permission would have been needed. The commander believed he was performing a demonstration flight; however, because more than the minimum flight crew was on board, permission would have been required from the CAA, but this had not been applied for.

Conclusion

The cause of the loss of engine power could not be determined, but the reported symptoms were consistent with a fuel system problem. Attempts to restart the engine were unsuccessful and the commander committed to a forced landing from about 1,100 ft agl. Although the commander's initial intention was to force land in a field, he became aware of a farm strip and probably made a late change of decision to land on the strip. This late decision, and the subsequent manoeuvres in the attempt to reach the strip, ultimately resulted in an unsuccessful forced landing and the aircraft struck the ground in a steeply left banked attitude.