AAIB
Air Accidents Investigation Branch

AAIB Bulletin 11/2020

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01252 512299

Air Accidents Investigation Branch
Farnborough House
Berkshire Copse Road
Aldershot
Hants GU11 2HH

Tel: 01252 510300
Fax: 01252 376999
Press enquiries: 0207 944 3118/4292
http://www.aaib.gov.uk

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(ALL TIMES IN THIS BULLETIN ARE UTC)

AAIB Field Investigation Reports

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

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

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

SERIOUS INCIDENT

Aircraft Type and Registration:	Boeing 737-8K5, G-TAWG
No & Type of Engines:	2 CFM CFM56-7B27E turbofan engines
Year of Manufacture:	2012 (Serial no: 37266)
Date & Time (UTC):	24 December 2019 at 0048 hrs
Location:	Manchester Airport
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 6 Passengers - 181
Injuries:	Crew - None Passengers - None
Nature of Damage:	Bearing failure, separation of No 4 (right outer) mainwheel and severe damage to the associated brake unit
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	41 years
Commander's Flying Experience:	6,709 hours (of which 246 were on type) Last 90 days - 68 hours Last 28 days - 27 hours
Information Source:	AAIB Field Investigation

Synopsis

Shortly after a normal touchdown, the right outer (No 4) mainwheel separated from its axle and was seen, by the pilots, to pass down the right side of the aircraft. The aircraft vacated the runway and was safely brought to a halt on the taxiway. The wheel separated as a result of a failure of the inboard wheel bearing which led to the failure of the outer bearing. The exact cause of the initial failure to the inboard bearing could not be determined.

History of the flight

The aircraft landed on Runway 23R at Manchester Airport after an uneventful flight from Al Massira Airport (Morocco). The co-pilot was PF and as the aircraft slowed to approximately 80 kt he handed control to the commander. At approximately 60 kt the pilots became aware of an object overtaking them at high speed, on the right, along the edge of the runway. ATC informed the pilots that the aircraft may have suffered a tyre problem. The aircraft was slowed to 10 kt, before it vacated the runway onto a taxiway. The pilots reported no handling abnormalities other than a slight judder as the aircraft vacated the runway.

The Airport Fire and Rescue Service attended the aircraft and informed the commander that the right outboard wheel (No 4) and tyre had completely detached, with significant damage to the brake pack. The aircraft was shut down and after consulting with the operator's engineers, it was decided to disembark the passengers prior to any further movement of the aircraft. The passengers disembarked onto the taxiway and were taken by bus to the terminal.

The aircraft was towed to the parking area where a detailed examination was carried out by the operator's engineers.

Debris trail

Marks and debris on the runway indicated that the wheel detached approximately 1,800 m from the threshold and continued for a further 700 m before coming to rest on the grass to the right of Runway 23R, between Taxiway AF and AG. A runway inspection carried out immediately after the landing found metallic debris from the wheel hub, bearings and brake pack strewn along the runway from point P to an area where most of the debris was found, abeam Taxiway BD (Figure 1).

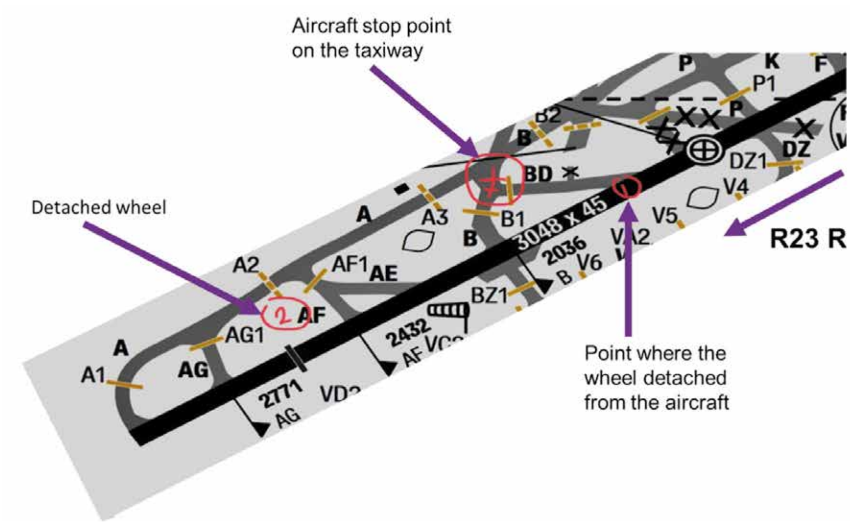


Figure 1

Final location of aircraft, debris and wheel as plotted by airport authorities

Recorded information

The CVR and FDR were downloaded but held no relevant information to help determine why the mainwheel separated from the aircraft.

Aircraft details

G-TAWG is a Boeing 737-8K5, passenger aircraft. It was built in 2012 and had accrued approximately 29,000 flight hours and had a valid airworthiness review certificate.

The aircraft is fitted with tricycle retractable landing gear with two wheels fitted to each landing gear leg. All the wheels can rotate independently of each other. The right mainwheel assembly was fitted to the aircraft on 14 November 2019 and had accrued 130 cycles.

Landing gear, wheels and brakes

Main wheels

The main wheels, which are designed to allow easy replacement, are fitted to fixed stub axles and are held in place by a single wheel nut and washer. The wheel nut is secured by locking bolts.

The wheels are of a split hub design with the hubs containing the inboard and outboard tapered roller bearings (Figure 2). The outer bearing component is known as the cup and the inner bearing component as the cone. The cup bearing raceway is an interference fit within the hub, and the cone is a sliding fit on the stub axle. The rollers run on tracks in the cone and cup. The track on the cone is defined by a rib around its edges; there are no ribs on the cup. The inboard and outboard bearing assemblies are fitted with external grease seals which are held in place by spring steel retaining rings located in grooves in the wheel hub. The general arrangement of the inboard and outboard bearings is shown in Figure 3.

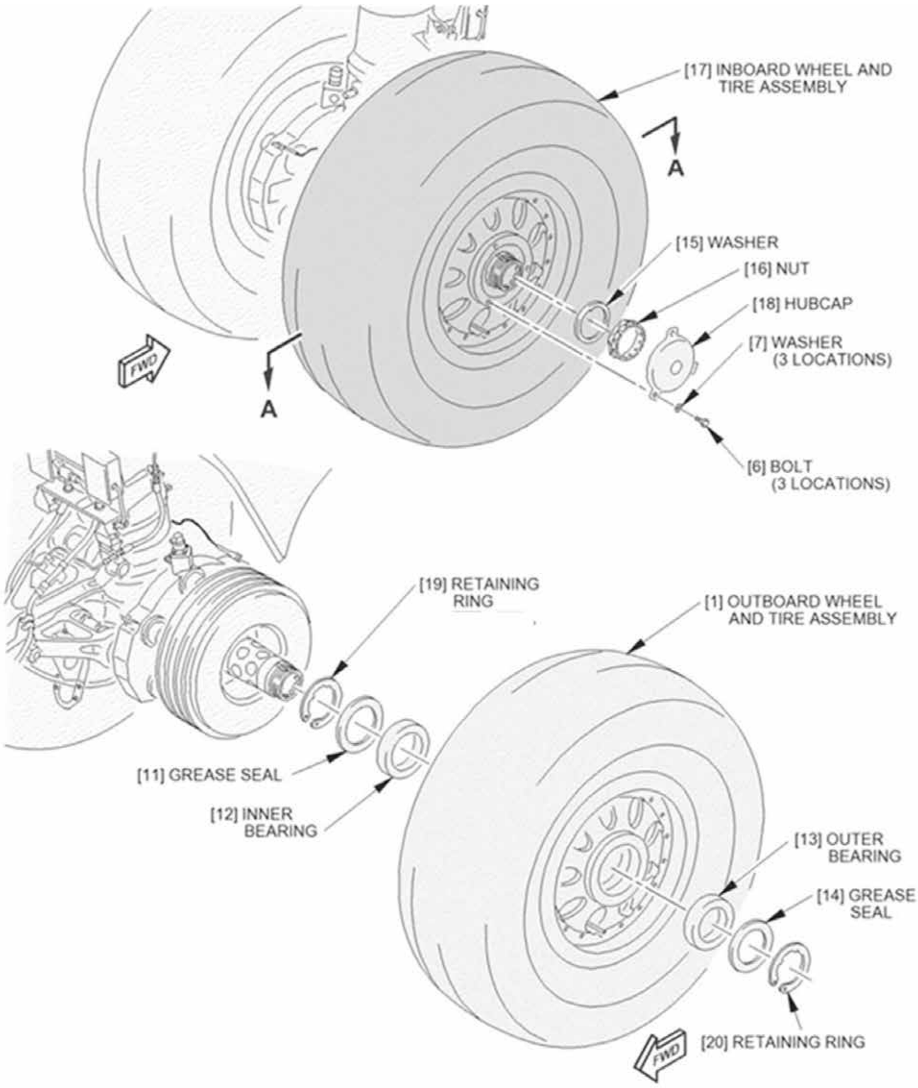


Figure 2

Landing gear mainwheel general arrangement (courtesy of Boeing)

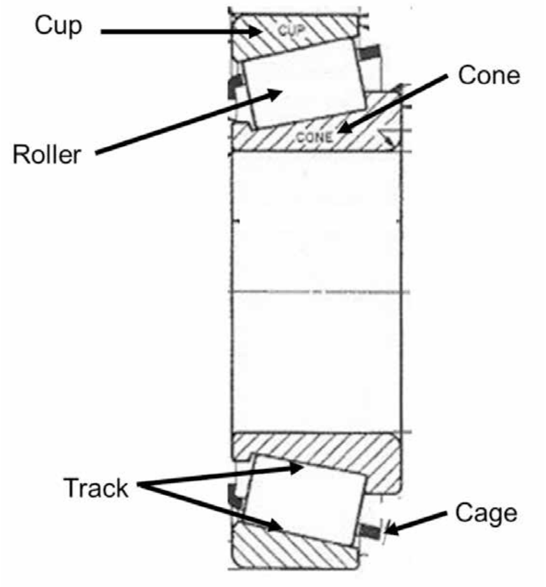


Figure 3

Bearing general arrangement (courtesy of Timken)

Standard wheel bearing assembly practice

The bearings are provided as part of the wheel assembly. When fitted to the axle, a nut and washer are used to apply pressure to the bearings, which is known as the preload. The preload ensures the bearing cups and cones are correctly seated, and the rollers correctly aligned. This is achieved by applying a torque to the nut using a suitable torque wrench. Once the bearing assembly has been preloaded, the nut is loosened slightly, whilst maintaining a tight contact between the cup, cone and rollers, then retightened to its service torque, which is usually about 20-25% of the preload torque. Both these procedures are done whilst slowly rotating the wheel clockwise to ensure that the large roller ends are seated against the cone rib.

Brake units

All four main wheels are fitted with multiple rotor and stator brake packs. The rotors are single piece carbon ceramic discs with equally spaced radial key slots which engage with a set of bars, known as rotor drive keys, rigidly mounted on the inner surface of the wheel hub.

The torque tube and reaction plate, which constitute the main frame of the brake pack, are fixed to the lower part of the landing gear axle boss (Figure 4). A set of friction stators are positioned on the outside and between each of the rotors and are prevented from rotating by locking in ridges radially spaced around the torque tube.

When hydraulic pressure is applied to the brake pack, a set of six pistons, equally spaced around the brake housing, impart a compressive force against the reaction plate on the end of the torque tube. This creates a braking effect between the rotors and stators. The brake reaction loads are imparted into the landing gear structure via the torque reaction recesses.

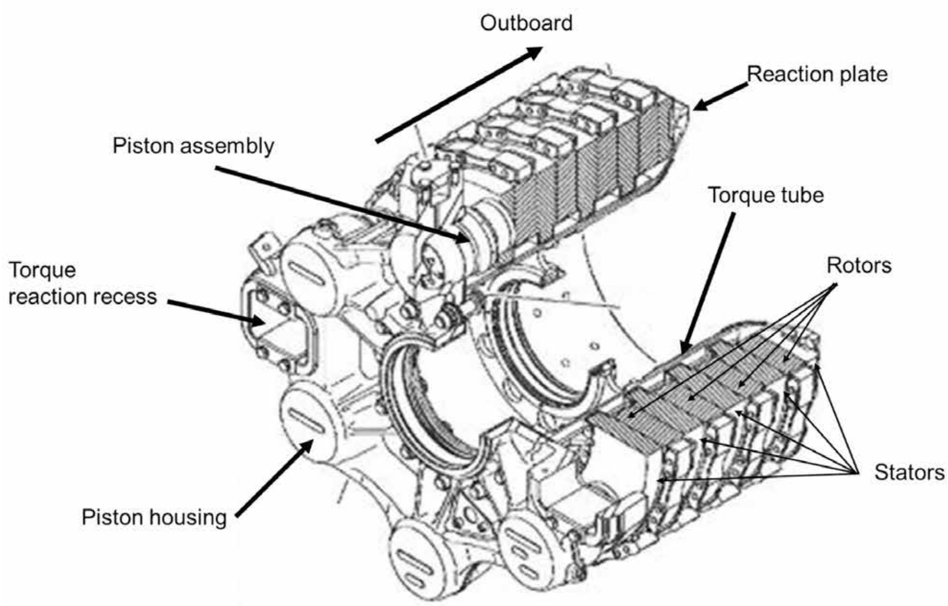
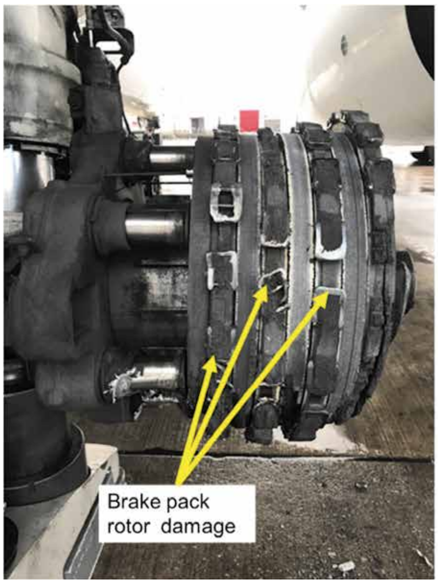
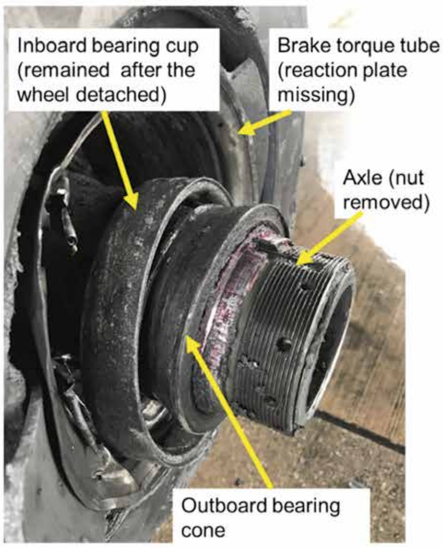


Figure 4
Brake assembly components

Initial examination

Prior to moving the aircraft, an inspection was carried out by the operator's engineers who found significant damage on the brake pack and to the wheel bearing cones, which were still attached to the axle. The tracks were heavily scored, exhibited heat damage and the remains of some of the rollers were smeared onto the bearing tracks. The inboard bearing cup had detached from the hub and was loosely hanging on the axle (Figures 5 and 6). The nut and washer were still in place on the axle and were relatively undamaged. The brake pack reaction plate was found on the runway.





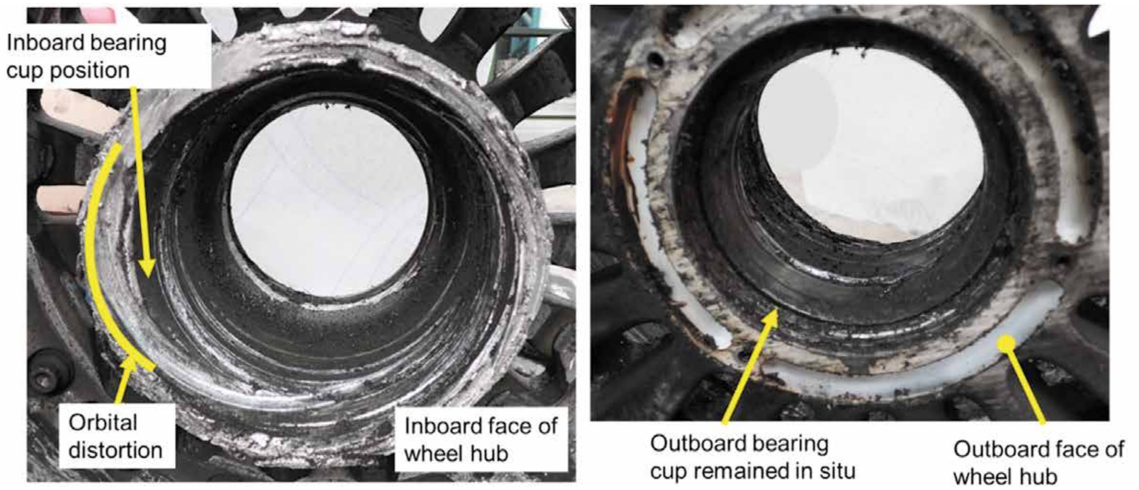
Figures 5 and 6
Brake pack and bearing damage

Detailed examination

A detailed examination of the wheel and brake components was carried out at the AAIB premises by the AAIB and a representative from the bearing manufacturer.

Wheel hub

All but one of the brake rotor drive keys had detached and the inner face of the hub was heavily scored over its entire surface. The outboard bearing cup was in place, but the inboard bearing cup had detached. The hub, where the inboard cup had been fitted, was badly distorted and had taken on an offset elliptical shape (Figures 7 and 8).



Figures 7 and 8

Hub damage around the inboard and outboard bearing cup area

Brake pack

The brake pack rotors and stators were all present, although they had been pushed outwards by the brake pistons which had travelled to their full extension. There was no evidence of hydraulic fluid leakage. The outer reaction plate had detached along with a large portion of the brake torque tube. Some of the lower-most pistons had deep gouges in their outer surfaces. Most of the rotors and stators were distorted and had various cracks and fissures across their surfaces. Figure 9 shows the damage to the brake pack torque tube and pistons.

Axle, wheel nut and spacer

Apart from debris and light scratch marks, the axle appeared to be undamaged. The wheel nut and washer remained in place and were removed by the operator after the event. Examination found the washer to be in relatively good condition and there was some scoring and indentation on the nut flats.

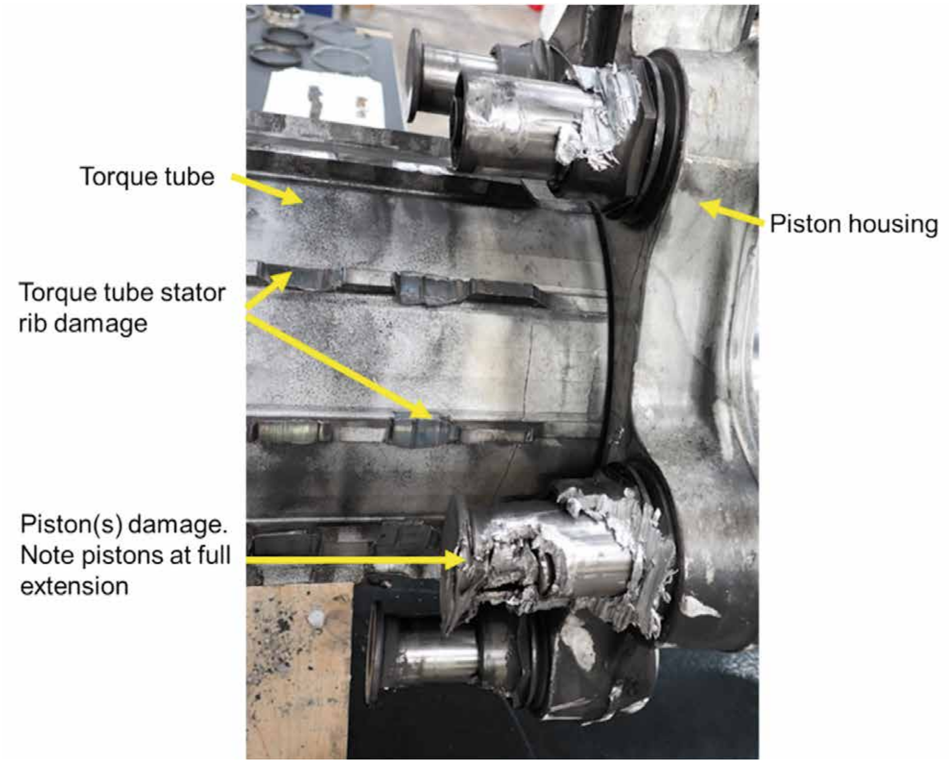


Figure 9
Damage to the torque tube and pistons

Bearings

Only 20% of the outboard and 50% of the inboard bearings were recognisable. The outboard bearing cone, which was still fitted to the axle, was scored and showed evidence of metallic smearing on its bearing track. None of the rollers or the cage were in place. The remains of the rollers were found on the runway and showed signs of skidding welding and overheating. The outboard bearing cup remained within the wheel hub and exhibited similar damage to the bearing cone.

The damage to the inboard bearing was far worse than on the outboard bearing components. The inboard cone was severely overheated, its bearing track was worn and misshapen and the remains of several rollers were smeared and welded to its surface. The inboard bearing cup exhibited very similar damage to the cup on its bearing track. Figures 10 and 11 show the condition of the outboard and inboard bearing cones.

The cages from both bearings had been reduced to deformed fragments which showed similar extreme levels of heating and distress as the rollers. There were minute quantities of grease present on the remains of the grease seals and significant carbonised grease deposits on some of the bearing debris.

Figure 10
Outboard bearing cone

Figure 11
Inboard bearing cone

Aircraft maintenance history

Fitment of the wheel assembly

The wheel was overhauled on 11 November 2019, released to service on 14 November 2019 and fitted to G-TAWG on 25 November 2019. The following entry was made in the maintenance work order:

> *'G-TAWG WO 1200 1621*
> *No 4 m/wheel worn to limits*
> *No 4 m/wheel assy replaced iaw AMM 32-45-11, final TQ 150ft/lbs #8007'*

The number #8007 identifies the torque wrench used to apply the service torque. The licenced engineer who replaced the wheel reported that there was nothing abnormal about the task and that the replacement wheel was serviceable. He was satisfied that the bearings had been correctly fitted and were properly greased. Regarding the application of the torque, the engineer said he always set the torque wrench to 550 lbf-ft, which was in the middle of the required range. Similarly, he would set the service torque to 150 lbf-ft and that a small clockwise, movement of the nut, as specified in the Aircraft Maintenance Manual (AMM), was only ever required to align the locking bolt holes between the nut and the axle.

Torque wrench

The torque wrench used by the engineer for the preload, #WS3045, has a range of 480 to 940 Nm, equivalent to 354 to 693 lbf-ft, and the required torque is set using a small retractable crank handle located at the hand-grip end of the wrench. It is known as a 'break-out' torque wrench because an unmistakable audible 'click' is heard and a 'jolt' felt through the handle when the required torque is reached.

On 8 January 2020, just over two weeks after the event, the torque wrench used to apply the preload torque on G-TAWG underwent its annual calibration[1]. It was found to be under reading by 11% to 12% on each of the test settings: the allowable tolerance is ±4%. As a result of this finding, the torque wrench was withdrawn from service. No issues have been reported with the torque wrench used to apply the service torque of 150 lbf-ft. It is common practice for a torque wrench to be set and tested using a test gauge; however, when the wheel was fitted to G-TAWG there did not appear to be a test gauge readily available.

Clamping force

The outside diameter of the axle thread is 3.78 inches (96 mm) and the preload torque range results in a clamping force exerted by the nut on the bearings of 8,800 lbs to 10,600 lbs (4,000 kg to 4,800 kg). The effect of the torque wrench under reading would have reduced the force exerted by the engineer on the nut to 8,600 lbs (3,900 kg) which equates to 97.5% of the required minimum force.

Second occurrence of bearing failure

On 15 February 2020 another Boeing 737 in the operator's fleet, G-FDZB, suffered a mainwheel bearing failure, which was detected during the pre-flight inspection when it was observed that the wheel and brake assembly were covered in "silver glitter". The inboard bearing was subsequently found to have seized and there was severe damage to the wheel hub and brake assembly.

Due to the restrictions of the Coronavirus pandemic, at the time of writing the operator had not completed their investigation into the cause of this bearing failure, but once the situation allowed would take the following safety action:

> As a result of the No 4 inner wheel bearing failure found on Boeing 737-800, G-FDZB, and its similarities with a preceding bearing failure on Boeing 737-800, G-TAWG, a component failure investigation will be carried out to ascertain if there is a common cause for both failures.

Footnote

[1] Calibration Report Number 3209160001 issued to the operator on 25 February 2020.

Analysis

The right outer mainwheel (No 4) detached from its axle as a result of a failure of its wheel bearings.

Bearing operating conditions

During start up, pushback and taxi, the loaded bearing rotates slowly and gradually increases speed during the takeoff until eventually it slows and stops as the landing gear is retracted. During this period, the bearing gently warms and settles into running surrounded by a compliant lubricant.

The conditions during the landing are very different. The bearing hub and wheel assembly will have been 'cold soaked' at altitude and at touchdown the wheels and bearings will accelerate to landing speed with increasing load as the aircraft's aerodynamic lift reduces. These conditions do not normally present a problem; however, the landing conditions can exacerbate any faults or wear and lead to premature failure of the bearing assembly.

Sequence of events leading to the wheel detaching

The inboard bearing was more severely damaged than the outboard bearing indicating that the inboard bearing failed first, causing secondary damage to the outboard bearing. The severity of the damage to the inboard bearing indicates that it may have been running for a period of time in a distressed condition during which large amounts of heat were generated.

The elliptical damage to the hub, and the area where the inboard bearing cup is located, is consistent with the inboard bearing becoming loose allowing the wheel to wobble about its axle.

With a loss of wheel alignment, the outboard bearing would have deteriorated until the rollers and cage were released. Damage to the brake components show that as the bearings failed, the wheel loads were imparted into the brake components leading to the torque tube failure. The brake pistons then had nothing to react against, so fully extended under hydraulic brake system pressure. The damage to the hub and bearings was such that the wheel was able to move outwards over the outboard bearing cone, washer and nut until the wheel eventually came off the axle.

Possible causes

The bearings were too badly damaged to determine why they failed, but damage can be caused by:

- Insufficient or poorly applied grease
- Incorrect handling
- Incorrect type of grease
- Break down of the grease properties
- Excessive grease (not a common occurrence)
- Ingress of water, debris or other contaminants

- Incorrect assembly, by misalignment or by incorrect preload
- Sudden shock loading whilst stationary
- Overload during rotation
- Wear and gradual degradation of the rolling surfaces over time

The following aspects were considered during this investigation.

Damaged during the landing

The aircraft had not been subjected to a heavy landing since the wheel had last been fitted. Therefore, the possibility that the bearing assembly failed as a result of excessive landing loads was discounted.

Poorly prepared bearing

Pre-installation inspection of the wheel and bearing assembly, prior to being fitted to the aircraft, was carried out by the engineer. The engineer identified nothing abnormal and reported that the bearings had been greased correctly.

Pre-existing faults

The severity of the damage to the bearing components make it impossible to identify any pre-existing faults, or damage, or the presence of excessive moisture in the grease. Water ingress is known to cause a rapid degradation of bearings of this type.

Debris

The inboard and outboard bearing assembly was too badly damaged to establish if any debris (metallic, grit or dust) had initiated their failure.

Insufficient preload

The importance of applying the correct preload while rotating the wheel is emphasised by the bearing and aircraft manufacturer. There was no evidence that the correct preload procedure was not applied when the wheel was fitted.

The torque wrench used (#WS3045) was calibrated and certified by the manufacturer and was required to be tested annually. It was last calibrated in January 2019 and was found to be out of calibration five weeks after the event. It is good practice to check the torque set on the torque wrench prior to use, but this is not a mandatory requirement and, as in this case, it may not always be possible to ensure that a suitable test set is readily available.

It is not known how long the torque wrench was over reading or the likely error when the wheel was fitted. If it was over reading by 11% to 12% then the actual torque applied could have been as low as 484 to 489 lbf-ft, which is slightly below the minimum requirement of 500 lbf-ft. Consequently, the compressive force applied to seat the bearings might have been 3,900 kg, which is 100 kg below the minimum requirement of 4,000 kg. However, this relatively small reduction in force is not considered sufficient on its own to have caused the bearing to fail.

Conclusion

Bearing failure investigations such as this are often inconclusive due the severity of the material damage within the bearing destroying evidence of the initiation. Therefore, it was not possible to determine the cause of the bearing failure, or to discount the possibility that there was a pre-existing fault, or the bearing had become damaged as a result of the ingress of debris or moisture.

It is possible that preload torque applied was slightly below the minimum required; however, it was still considered enough to ensure that the bearing assembly was correctly seated and makes it unlikely to have affected the bearing running condition. However, a combination of the possible causes set out in this report cannot be ruled out.

The AAIB will review the findings of the operator's investigation into the bearing failure on G-FDZB and will provide an update to this report if it provides further clarification on the cause of the bearing failure on G-TAWG.

Published: 1 October 2020.

SERIOUS INCIDENT

Aircraft Type and Registration:	DHC-8-402, G-FLBE
No & Type of Engines:	2 Pratt & Whitney Canada PW150A turboprop engines
Year of Manufacture:	2009 (Serial no: 4261)
Date & Time (UTC):	14 November 2019 at 1950 hrs
Location:	In-flight from Newquay Airport to London Heathrow Airport
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 4 Passengers - 59
Injuries:	Crew - None Passengers - None
Nature of Damage:	Aileron cable broke
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	51 years
Commander's Flying Experience:	8,778 hours (of which 5,257 were on type) Last 90 days - 150 hours Last 28 days - 33 hours
Information Source:	AAIB Field Investigation

Synopsis

Shortly after takeoff in a strong crosswind, the pilots noticed that both handwheels[1] were offset to the right in order to maintain wings level flight. The aircraft diverted to Exeter Airport where it made an uneventful landing.

The handwheel offset was the result of a break in a left aileron cable that ran along the wing rear spar. In the course of this investigation it was discovered that the right aileron on G-FLBE, and other aircraft in the operator's fleet, would occasionally not respond to the movement of the handwheels. Non-reversible filters were also fitted to the operator's aircraft that meant that it was not always possible to reconstruct the actual positions of the control wheel, column or rudder pedals recorded by the Flight Data Recorder.

The aircraft manufacturer initiated safety actions to improve the maintenance of control cables and to determine the extent of the unresponsive ailerons across the fleet. Three Safety Recommendations are made in this report for the unresponsive aileron and filtering of the control position data.

Footnote

[1] The handwheel is also commonly referred to as control wheel or yoke. In this report the term handwheel is used.

History of the flight

The pilots were operating a four-sector duty with two return flights from Newquay Airport (Newquay) to London Heathrow Airport (Heathrow). The first sector was uneventful, and the pilots reported no technical issues with the aircraft. On the second sector, the weather reported at Newquay was strong northerly winds with turbulence at lower levels and a gusting crosswind that would have been close to the aircraft's limit[2] of 32 kt. The aircraft landed at 1723 hrs.

The commander considered that the landing at Newquay was firm and was concerned that it may have constituted a heavy landing, so called for engineering assistance. The operator's Maintenance Control checked the flight data from the aircraft's wireless Quick Access Recorder and dispatched an engineer to examine the aircraft. The pilots were subsequently informed that the landing had been within limits and the aircraft departed for Heathrow around 25 minutes late at 1914 hrs.

Due to the strong gusting wind conditions, the plan was for the commander to act as PF for the departure with the co-pilot assuming control once airborne. Routine control checks were carried out during the taxi and appeared to be normal. The pilots described the conditions during the departure as "quite rough with a lot of drift". At the acceleration altitude of 1,000 ft aal, the commander engaged the autopilot (AP) and passed control to the co-pilot who made a right turn, using the AP, towards the reporting point DAWLY.

The co-pilot stated that he felt that the aircraft "struggled" to maintain the right turn. He, therefore, informed the commander that there was an issue with the controls and that the handwheel was deflected significantly to the right to maintain wings level. The commander, who had not noted any difficulty in controlling the aircraft in manual flight, recalled that the handwheel was not in the correct position and was displaced to the right by around 30° to 40°. He also reported that the trim was in the normal position and the spoilers were retracted.

The commander took control and noted that the displacement of the handwheel was the same with the AP disengaged, and when flown manually the aircraft felt in trim with no unusual feedback through the controls. The AP was reselected, and control passed back to the co-pilot. The pilots discussed the issue and decided to stop their climb at FL200. The co-pilot recalled that the handwheel deflection increased with increased airspeed, which he considered was due to the scheduled de-activation of the outboard spoilers at 170 KIAS.

The commander contacted his company operations to seek engineering advice. As the response did not help his understanding, he informed operations of his intention to divert to Exeter Airport (Exeter) as it was a company engineering base. He requested a direct track to the EX NDB, which was approved by ATC, and the commander briefed the cabin crew on the situation. As the aircraft descended towards the NDB the co-pilot noticed that the control deflection required to maintain wings level was increasing. During this period, the pilots consulted the Quick Reference Handbook (QRH) but found no checklists that they

Footnote

[2] The crosswind limit is for wet and dry conditions.

considered relevant. As the aircraft neared the NDB the cabin was not ready for landing, so the commander decided to join the Hold. As the airspeed reduced, the outboard spoilers became active and the crew recalled that the handwheel deflection reduced. The crew declared a PAN to Exeter ATC.

The commander stated that as the handwheel was deflected to the right, it would be preferable to fly left turns and, therefore, made this request to ATC. Once the cabin was secured, the aircraft was positioned for a left-hand downwind leg for an approach to Runway 08 with the commander as PF. The weather conditions at Exeter were better than at Newquay with only a slight crosswind from the left during the approach. The commander deselected the AP earlier than normal and recalled a slight pull to the right on the handwheel, but felt the aircraft was completely controllable. The approach and landing were uneventful, and the aircraft landed at 1955 hrs.

Aircraft damage

Post-flight examination revealed that the lower left aileron cable broke just outboard of the engine where it passed over a pulley to accommodate a change in the wing dihedral (Figure 1). There was no other damage to the aircraft.

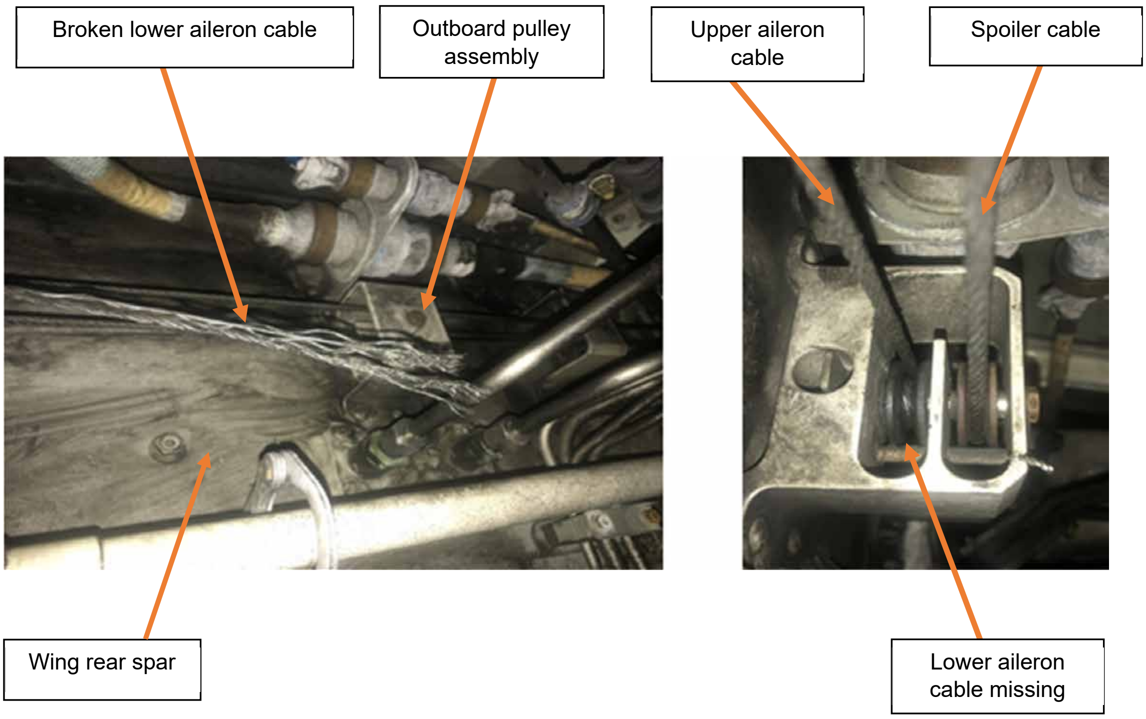


Figure 1

Broken aileron cable and associated pulley

Personnel information

Both pilots were experienced, with the co-pilot recently having been employed as a direct entry commander: the operator required direct entry commanders to operate as a co-pilot for three months prior to transitioning to command.

Aircraft information

The De Havilland Canada Dash 8-402 (DHC-8-400[3]) is a high wing, two pilot, transport category aircraft, with seating for up to 78 passengers and powered by two turboprop engines.

G-FLBE was manufactured in 2009 and had accrued approximately 22,400 flying hours. It was certified against the requirements of Canadian Airworthiness Manual 525, which is applicable to Transport Category Aeroplanes.

Aircraft roll control systems

Roll control is achieved using a combination of ailerons and spoilers.

Ailerons

Roll inputs are mechanically transmitted from the pilot's handwheels to the ailerons through a series of quadrants, cables, levers and pushrods. Movement of the handwheels causes the ailerons to deflect asymmetrically and in proportion to the handwheel rotation. Aileron position is not shown on the cockpit instrumentation.

Spoilers

The spoilers are a secondary flight control system. There are two hydraulically powered spoilers on each wing identified as inboard and outboard. The inboard spoilers operate across the full speed range; the outboard spoilers are automatically de-activated above 170 kt and are reactivated as the aircraft decelerates through 165 kt. The position of all four spoilers is shown on the cockpit instrumentation.

Autopilot and trim

The Automatic Flight Control System provides roll commands through the AP servo. The AP automatically disconnects if the force at the handwheel exceeds approximately 17.5 lb.

Roll disconnect system

The left pilot's handwheel is connected to the spoiler control circuit and the right pilot's to the aileron control circuit. Under normal operations the handwheels are connected to each other so that either handwheel operates both circuits at the same time. If either control circuit becomes jammed, a roll disconnect handle in the cockpit can be operated to disconnect the aileron system from the spoiler system. The pilot with the unjammed controls would then control the aircraft in roll.

Aileron and spoiler control cables on the wing rear spar

The aileron and spoiler control cables are routed along the wing rear spar. These control circuits are closed-loops[4] consisting of upper and lower cables with turnbuckles to set a

Footnote

3 In this report, DHC-8-400 is used to refer to the -402 and other derivatives of the -400 series of aircraft.
4 Closed-loop in this sense refers to a flying control system with two cables in tension such that when one cable moves, the other cable remains in tension but moves in the opposite direction. The flying control surface is attached to both cables.

nominal tension of 97 lb (+/- 2.5 lb) adjusted in accordance with the AMM for variations caused by the local air temperature. There is no other cable tensioning device in either control system.

Immediately outboard of the engine, small pulleys direct the cables by approximately three degrees to accommodate a change in the wing dihedral. The spoiler cables are routed aft of the aileron cables (Figure 2).

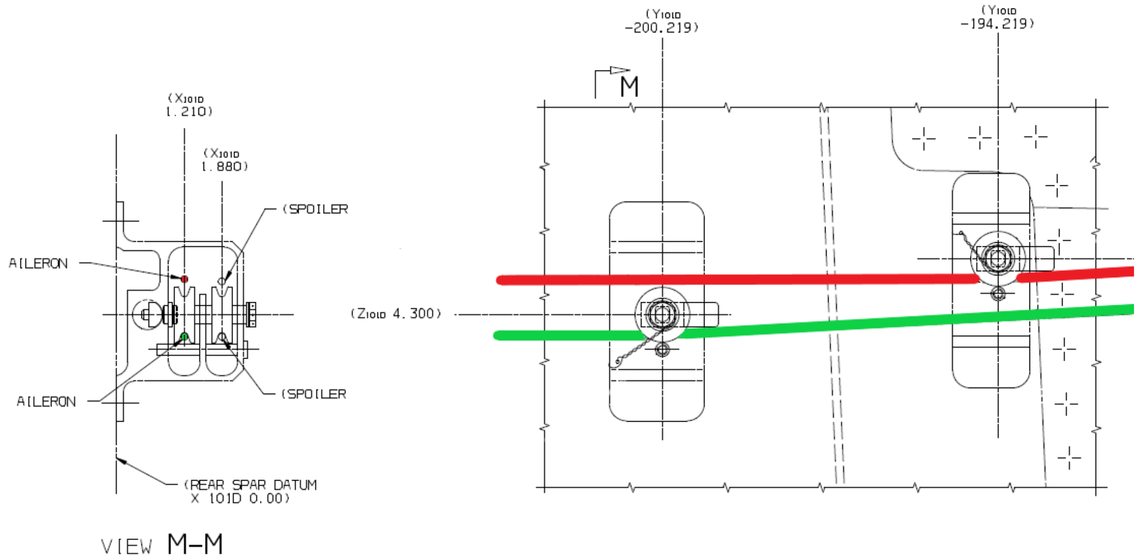


Figure 2

Pulley and cable arrangement to accommodate a change in the wing dihedral

Construction of the control cables

The control cables have a diameter of ⅛ inch and are constructed from 7 strands, each consisting of 19 wires. Six of the strands are wound concentrically around a central strand (Figure 3).

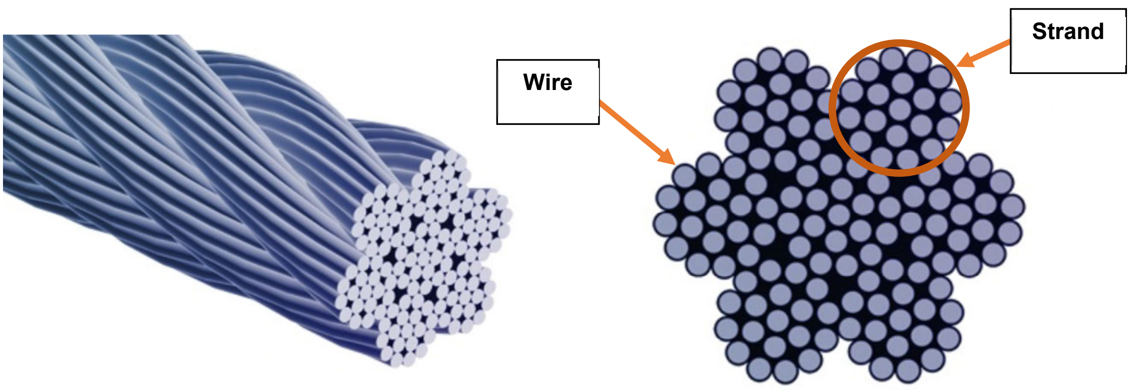


Figure 3

Construction of the control cable

Meteorology

The Met Office provided the following summary of the weather at Newquay for when G-FLBE departed at 1914 hrs:

> *'From the information available, it can be concluded that the meteorological conditions on the 14th November 2019, in the area around Newquay at around 1900 UTC, were strong winds with a band of cloud and rain. The observational data shows evidence that at the time of departure, surface wind speeds were 22-24 KT with gusts 32-36 KT at 020 degrees. Forecast data from both the F214 and Ballooning forecast also indicate that likely wind speeds at 500 and 1000 FT would have been around 30 KT and 40 KT respectively. Forecast data from the F215 low level weather chart indicated that at the time of interest there would likely have been moderate to severe low-level turbulence in the vicinity of Newquay'.*

Relevant QRH checklists

The pilots consulted the operator's QRH during the transit to Exeter but did not find any checklists that they considered relevant. However, the QRH contains a checklist for *'Roll Control Malfunction - Aircraft rolls with no Control Wheel* [Handwheel] *Input'* (Figure 4), which the manufacturer advised was relevant.

ROLL CONTROL MALFUNCTION
(Aircraft rolls with no Control Wheel input)

- Roll Control.................................APPLY TO HOLD WINGS LEVEL

IF CONTINUOUS ILLUMINATION OF SPLR 1 OR SPLR 2 PUSH OFF SWITCHLIGHTS IN WINGS LEVEL FLIGHT:
- Illuminated Switchlight...PUSH OFF

OTHERWISE, IF SPLR 1 OR SPLR 2 PUSH OFF SWITCHLIGHTS DO NOT ILLUMINATE:
- Power...APPLY
- Airspeed..INCREASE

IF SPLR 1 OR SPLR 2 PUSH OFF SWITCHLIGHTS PUSHED OFF:

Note » The SPLR OUTBD caution light will illuminate below 150 KIAS, the ROLL SPLR INBD GND and ROLL SPLR OUTBD GND caution lights will illuminate on landing.

LANDING CONSIDERATIONS:
» Land at an airport with minimal crosswind and turbulence using flap 15 or 35.
» **Landing distance – Page 2.3 Non-Icing, 3.3 Icing – Item 5**
- **END**

OTHERWISE:

LANDING CONSIDERATIONS:
» Land at an airport with minimal crosswind and turbulence using flap 15 or 35.
» Non-Icing and Icing VAPP and VREF speed increase by 7kts.
» **Landing distance – Page 2.3 Non-Icing, 3.3 Icing – Item 6**

Figure 4

QRH Roll Control Malfunction checklist

The pilots stated that the handwheel had to be displaced by up to 40° to the right to maintain level flight, which can be considered as an uncommanded roll to the left. The checklist commences with an action on Roll Control and states '*APPLY TO HOLD WINGS LEVEL*'. The next action concerns the spoilers and, as was the case on the event flight, if the SPLR 1 or SPLR 2 captions have not illuminated the pilots are instructed to apply power and increase airspeed, but are not advised by how much. The manufacturer advised that the intent of increasing airspeed is to improve roll authority with the remaining controls.

The second part of the checklist addresses the landing considerations and directs the crew to land at an airport with minimal crosswind and suggests the use of either Flap 15 or 35. However, the manufacturer stated that any allowable landing Flap setting would be acceptable and the aircraft was cleared to land with Flap 10, 15 or 35; it was only the operator's version of the QRH that restricted the choice of Flap. The manufacturer advised that consideration of minimal crosswind was a generic expression that they used in a number of checklists and the intention was to remind pilots to consider the 'retained lateral control authority for landing'. Therefore, commanders should select an airfield which has the lowest crosswind component.

The checklist also directs the pilots to use the non-normal Landing Distance Required (LDR) table in the QRH. As the pilots felt that the QRH was not relevant, they did not complete these actions and instead used the normal V_{REF}[5] and landing distance. The runway at Exeter was sufficiently long for the increased LDR.

Recorded information

Recorders

The aircraft was fitted with a Flight Data Recorder (FDR), QAR and a 120-minute duration Cockpit Voice Recorder (CVR). The FDR recorded the incident flight and 23 previous flights. The CVR recording of the flight had been overwritten because the circuit breakers for the electrical power supply had not been pulled after the aircraft landed as the operator initially considered that the event was not reportable to the AAIB.

Salient parameters on the FDR included the position of the handwheels and control columns[6], the inboard and outboard spoilers and the right aileron. The Regulator did not require the left aileron to be instrumented as it is possible, during normal operation, to derive its position from the right aileron.

Previous landing at Newquay Airport

During the approach and landing at Newquay there were fluctuations in the aircraft's airspeed, roll and pitch, with rapid movements of the handwheels to maintain a wings level attitude. This movement was consistent with the turbulent weather conditions. As

Footnote

5 V_{REF} is the Reference Landing Approach Speed. The speed of the aircraft when it is at a height of 50 feet above the landing runway threshold if the calculated landing performance is to be achieved.

6 The left and right handwheel positions are required to be recorded because the left and right controls may be disconnected from each other in flight.

the aircraft touched down, a peak normal load of 2.01 g was recorded (a heavy landing inspection is required if the normal load exceeds 2.10 g). The aircraft briefly bounced before touching down for a second time with a normal load of 1.54 g, following which it then settled on its landing gear.

There was no offset in the handwheels during the flight from Heathrow to Newquay.

Flight from Newquay to Exeter

During the takeoff and initial climb from Newquay, the handwheels were at an average position of 23° clockwise (CW) to maintain a wings level attitude. An average handwheel position of 4° CW was required to maintain wings level during the two previous takeoffs from Newquay earlier the same day using the same runway. The wind speed and direction[7] were similar during all three takeoffs.

As the aircraft climbed through 1,000 ft aal, the AP was engaged (Point A Figure 5) and the aircraft started the right turn (Point B Figure 5), initiated by the pilots, towards DAWLY. When the aircraft's airspeed increased to 170 kt the outboard spoilers automatically deactivated and moved to their stowed positions. At 6,000 ft the aircraft rolled wings level, but the handwheels remained at about 20° CW (Point C Figure 5). The right aileron and right inboard spoiler were at +6° and 8° respectively (full range of aileron and spoiler movement is +/-17° and 75° respectively).

The full range of movement of the handwheels is 140° (70° CW and 70° anti-clockwise from the neutral position). Therefore, at 20° the handwheels were at 28% of their full CW range of movement. About 30 seconds later, the AP was manually disconnected as the commander assessed the roll control of the aircraft. The AP was then engaged, and the aircraft subsequently levelled at FL200.

At 1930 hrs, the aircraft altered course towards Exeter. While descending, the aileron trim was adjusted but this did not alter the CW handwheel offset. The aircraft entered a left descending Hold before positioning onto a left downwind approach. During these left turns, which were flown at airspeeds of between 200 kt and 187 kt, the handwheels were at 33° CW to maintain a left bank of 30°. As the aircraft's airspeed reduced below 165 kt, the outboard spoilers assisted with roll control.

When configured for landing with Flap 35 set and an approach speed of 123 kt, the handwheels were at 10° CW to maintain a wings level attitude. The AP was disconnected at 800 ft aal and the aircraft made an uneventful landing.

Modelling carried out by the manufacturer showed that the position of the left aileron and handwheel was dependent on a number of factors including the aircraft speed and direction of turn. When the handwheel was moved to the left, the intact cable on the left aileron would pull the surface upwards, but when moved to the right the tension in the

Footnote

[7] The reported wind during the event was from 010° at 23 kt, gusting 39 kt, and the wind during the previous departures had been from 020° at 24 kt, gusting 36 kt, and from 010° at 20 kt, gusting 30 kt.

intact cable would reduce and the aileron would be moved by aerodynamic loads. The manufacturer confirmed that the aircraft had sufficient roll authority with the left aileron in the most adverse position.

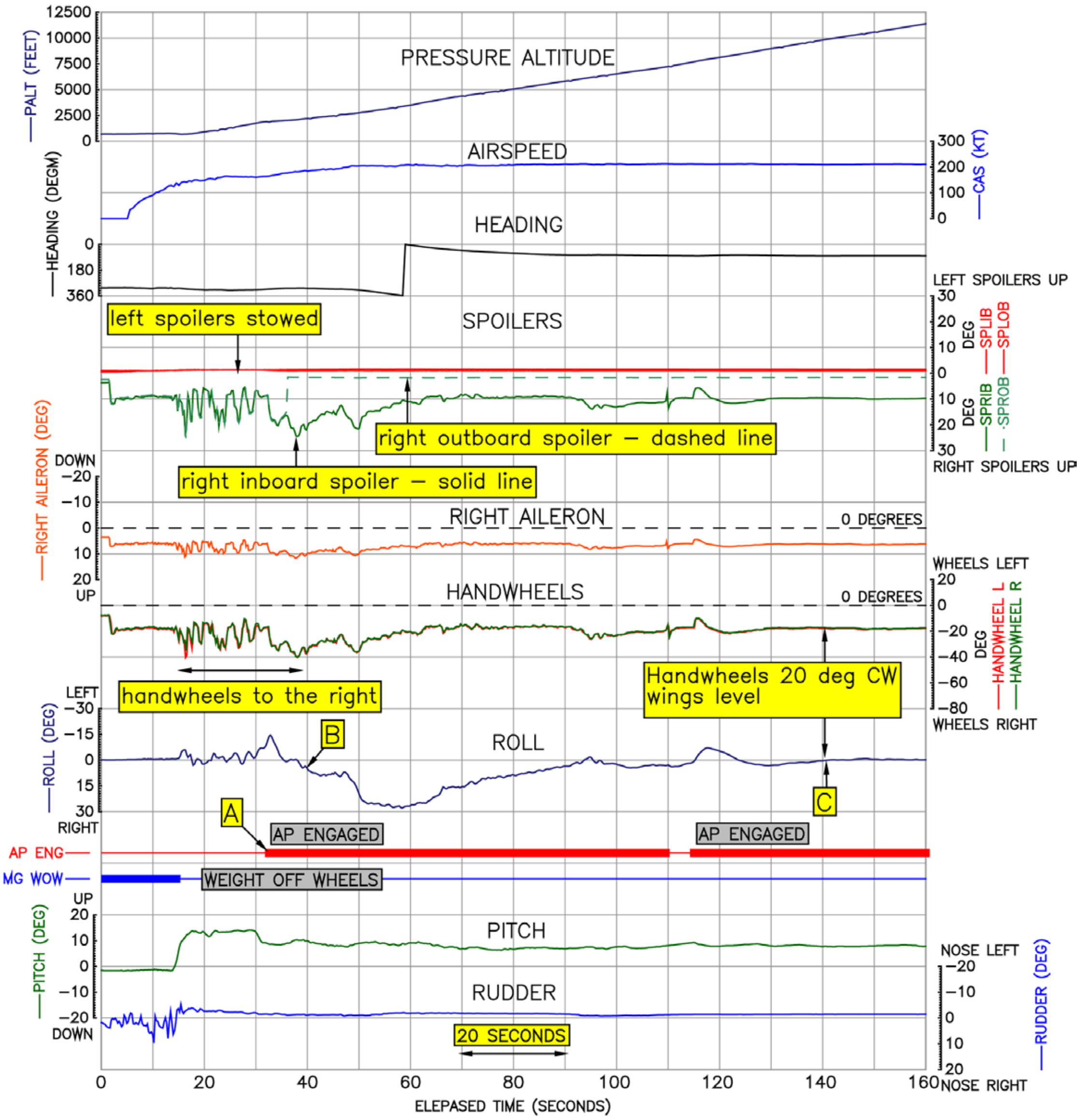


Figure 5

Handwheel offset after departing Newquay

On-aircraft examination

The lower left aileron cable failed where it passed over a pulley mounted on the rear wing spar. The pulley was found to rotate freely on its bearing.

When the handwheels were rotated through their full range of movement, the right aileron operated normally, whereas the left aileron remained in the fully up position. When the outboard section of the broken cable was pulled, the left aileron moved towards the neutral position and when released returned to the up position.

The broken cable was dirty and left a residue on a cloth when it was wiped. It was noted that there was a heavy accumulation of dirt on both sides of the aircraft where the aileron and spoiler cables ran along the inboard section of the rear spar. This heavy accumulation of dirt was also present on other aircraft in the operator's fleet.

Detailed examination of the cable and pulley

The cable and its associated pulley were examined using optical and scanning electron microscopes. Individual wires showed a variety of features including ductile (tensile overload) failure, wear between wires in adjacent strands, wear between wires in the same strand and wear from an external source. There was no evidence of manufacturing anomalies, corrosion or fatigue.

The pulley was found to be worn with a pronounced imprint of the cable around the entire circumference of the groove. Small particles of metallic debris were found embedded in the pulley and it was concluded that these originated from the control cable. Apart from the wear, dimensional checks of the pulley found it to be compliant with the drawing requirements.

G-FLBE maintenance history

The aileron cable had been fitted for six years and flown approximately 13,000 hours; it was visually inspected on five occasions. The last inspection was completed 10 months and 1,100 hours before the failure, when the tension of all four aileron cables on the rear wing spars was found to be below the minimum requirement. Maintenance records show that the cables were re-tensioned in accordance with the Aircraft Maintenance Manual (AMM).

Maintenance of cables

Aileron and spoiler control cables are 'on-condition'[8] and subject to a visual inspection and tension check every 2,500 hours. Preparation for this inspection includes removing external visible grease and dirt from the contact areas using a clean, dry cloth and a nylon brush with short bristles. If wear or fraying exceeds the limits defined in the AMM, and repair drawing, the cable must be replaced. If a new cable is installed the associated pulley can be re-used provided there are no flat spots on the groove and the pulley rotates freely.

There is no requirement to record the cable tension for trend monitoring and if cables are found to have insufficient tension the procedure instructs the maintainer to tighten the cable as required. There is no requirement in the AMM for operators to investigate the loss of tension, which might be indicative of a problem with the affected cable.

With regard to investigating the loss of cable tension, the Australian Civil Aviation Safety Authority issued a general Airworthiness Bulletin 27-012[9] in 2011 which advised:

Footnote

8 On-condition is preventive maintenance that requires a system, component, or appliance be inspected periodically or checked against some appropriate physical standard to determine if it can continue in service. The standard ensures that the unit is removed from service before failure during normal operation.

9 https://www.casa.gov.au/files/awb-27-012-issue-1-aircraft-control-cable-systems (Accessed 13 March 2020).

'…maintenance personnel and operators to be vigilant whenever installing or adjusting any aircraft control system using the classic two cables in tension, closed–loop cable design, including primary flight control systems.'

'loss of control cable tension should be treated with suspicion and investigated as it could be an indication of incorrect assembly and impending failure.'

Manufacturer's previous actions to address cable wear

2004

In April 2004, the aircraft manufacturer issued an All Operators Message (AOM) 122[10], which advised that premature wear had been found in the aileron and spoiler control cables that run along the wing rear spar. The AOM cited two main causes: excess grease and low cable tension. Following these findings, the cable manufacturing process was modified to prevent the application of excess grease, and the aircraft maintenance procedures[11] were amended to increase the pre-stretch loading[12] of the cables prior to final tensioning.

In December 2004, the manufacturer issued Service Bulletin (SB) 84-27-26[13] to inspect aileron and spoiler cables for premature wear, excess grease and correct tension. Operators were asked to report back on damaged or worn cables. The SB required:

- Any cables that were found to be worn beyond the limits defined in the AMM[14] to be replaced.
- Any excess grease to be removed using a dry cloth.
- Cable tension to be checked and adjusted as necessary.

2007

In May 2007, AOM 224 was issued which highlighted that little feedback had been received in response to SB 84-27-26. One operator reported finding one 'severely worn' aileron cable and 17 of their 23 aircraft had at least one cable with wear beyond the allowable limits. In all cases the cable tension was below the limits specified in the AMM.

The AOM informed operators that the AMM had been amended to include cold weather tension limits and suggested that operators consider implementing a summer and winter check of the cable tensions on the wing rear spar. Operators were also advised that if the

Footnote

[10] Bombardier Q400 All Operators Message No. 122, Special Inspection of Aileron and Spoiler Control Cables.
[11] Q400 Aircraft Maintenance Manual Task 27-10-00-830-805, Aileron Splitter Quadrant to Aileron Terminal Quadrant Rigging.
[12] A cable will stretch when a load is applied. The amount of stretch depends on the elasticity of the material and the construction of the cable. Provided the elastic limit is not exceeded, the elastic component of the stretch will disappear when the load is removed. The stretch associated with the construction of the cable is variable and remains when the load is removed. Pre-stretching is the application of a defined load to allow the cable to settle before the final load is applied.
[13] Bombardier (de Havilland DASH 8) SB 84-27-26, Flight Controls – Aileron System and Spoiler System – Control Cable Wear – Special Inspection / Rectification.
[14] Q400 Aircraft Maintenance Manual Task 20-10-21-200-801, Inspection of Seven-by-Nineteen and Seven-by-Seven Control Cables.

cables had not been checked within the previous 24 months they should consider performing an inspection in accordance with SB 84-27-26. A repair drawing was issued to allow aileron cables, where the damage exceeded the limits in the AMM, to continue operating with up to 12 broken wires for another 500 hours subject to an inspection every 65 hours (L-check). This inspection period was reduced in 2015 to 50 hours.

In July 2007, AOM 228 was issued and explained why the cables that run along the rear wing spar are unusually susceptible to wear. The major contributing factors were listed as:

- Cable tension below the rigging requirement.
- Greater exposure to dirt and carbon brake dust thrown up by the landing gear.
- High vibration levels due to their proximity to the engine nacelle.

The AOM reported that the periodic visual inspection of the aileron and spoiler cables in this area had been reduced from 8,000 to 2,500 hours. A cable tension check, every 2,500 hours, had also been introduced.

2015

In December 2015, SB 84-27-68 introduced modified aileron and spoiler cables with the aim of reducing wear and extending the inspection interval. Modified cables have external polymer sleeves fitted over the sections that are in contact with the pulleys; modified pulleys were also introduced to accommodate the increase in diameter of the cable resulting from the addition of the sleeve. Embodiment was at the operator's discretion; modified cables had not been fitted to G-FLBE. Aircraft delivered from the manufacturer since December 2015 have the modified cables fitted.

Manufacturer's investigation

Examination of pre-modification aileron cables

The manufacturer reviewed the AAIB findings and examined two pre-modification aileron cables that were removed by the operator during their fleet inspection. They reported that both cables were excessively contaminated with grease and debris, and commented that this contamination would accelerate the wear of the cable strands [wires].

The manufacturer identified eight events where aileron cables had broken; three were identified because of anomalies in-flight and five were identified while the aircraft was on the ground. These events occurred between 2004 and 2019 and involved operators located in five different countries.

Examination of post-modification aileron cables

Examination of a post-modification aileron cable, that had accrued approximately 4,800 hours, found that the section of the cable under the polymer sleeve was clean with no evidence of contamination. Moreover, when the cable was sectioned, and examined in detail, there was little evidence of wear.

The manufacturer stated that there had been no operator-initiated returns of post-modification aileron cables apart from those returned as part of their sampling programme. Three operators participated in this programme with aileron and spoiler cables being examined after 4,000, 8,000, 12,000 and 16,000 hours in-service use. The manufacturer stated that the sampled cables showed no evidence of wear.

Rejection rates of aileron and spoiler cables

The manufacturer reported that the in-service rejection rate for spoiler and aileron cables was similar, but they had not been notified of any spoiler cables failing (breaking). A possible reason was that as the ailerons are reversible[15] control surfaces, the cables experience more cycles of small movements.

Loss of cable tension in-flight

With regard to a loss of cable tension in-flight, the manufacturer advised:

> *'As a characteristic of Dash 8 aircraft design, aileron wing cable tension decreases at higher altitude. Flight tests in 2009 with instrumented turnbuckles showed as much as 55% tension loss at max altitude. If the cable had marginal tension on the ground (either through lack of maintenance or due to broken strands), the tension could drop to zero in-flight.'*

Safety action

Following the event on G-FLBE, the manufacturer reviewed the periodic inspection procedure and proposed amendments. These included requirements to:

- Rub the cables with a clean cloth in both directions to catch on broken wires.
- Move the handwheel through its full range in order to ensure that the section of the cables that run along the rear wing spar can be examined.

The original procedure stated that the handwheel should be moved '*if necessary*' but it is not possible to see all the surfaces of the cable without moving the handwheel. The manufacturer anticipated that these safety actions would be completed during 2020.

Implications of a broken aileron cable

Effect on aileron control surface position

On the ground, if the lower aileron cable breaks, the tension in the upper cable will cause the aileron to deflect upwards, and conversely, if the upper cable breaks the aileron will deflect downwards.

Following the failure of a cable in-flight, the position of the aileron surface would be dependent on the aerodynamic loads (speed of the aircraft). Modelling of the FDR data by the aircraft

Footnote

[15] A reversible flying control system is a system where there is a direct link between the flying control surface and the pilot's controls. If the flying control surface is moved, the control input also moves.

manufacturer showed that the left aileron reached a "high trailing edge up" position during periods of the flight. This would result in an uncommand roll that requires corrective action by either the pilot or AP.

Severity of a broken aileron cable

Failure of an aileron control cable was assessed as Minor during the certification process where a Minor event is defined as:

> *'…failure conditions that would not significantly reduce aircraft safety, and would involve crew actions that are well within their capabilities. Minor failure conditions may include, for example: a slight reduction in safety margins or functional capabilities, a slight increase in crew workload, such as routine flight plan changes, or some inconvenience to occupants.'*

However, the flight test programme for the certification of the DHC-8-400 did not include flying with a disconnected aileron cable. Instead, aircraft performance and roll authority were evaluated by separating the handwheels, using the disconnect mechanism, and flying the aircraft using the spoilers while the co-pilot's handwheel, which is connected to the ailerons, was held in an offset position.

Manufacturer's risk assessment

The manufacturer conducted a risk assessment as part of this investigation. After considering the severity of the failure, and the number of reported arisings, they concluded that the risk associated with an aileron control cable failure was low.

Regulator's review of the severity classification

Transport Canada analysed the FDR data from this event and concluded that '*more than adequate control authority was available to the crew for continued safe flight and landing following the cable disconnect*'. The number of reported in-service arisings was within the certification requirements for a Minor event and they considered the manufacturer's proposed changes to the maintenance of the cables to provide adequate mitigation. They confirmed that the severity classification of Minor, which was applied during certification, remained appropriate.

Safety action taken by the operator

The operator had installed post-modification cables on 24 of their aircraft and was in the process of modifying the remaining 30 aircraft in their fleet when the cable failed on G-FLBE. An inspection of the unmodified aircraft, carried out following the cable failure, identified 18 aileron cables and several pulleys that required replacing, which had a time remaining to the next scheduled inspection of between 550 to 2,000 hours.

When the operator inspected the three remaining aileron cables on G-FLBE after the failure, they assessed that they were all serviceable. However, when the cables were inspected again, as part of the ongoing investigation, the operator decided to replace them.

As a result of these findings the operator accelerated their cable modification programme with the intention of completing it by the end of 2020. In the interim they reduced the inspection period for pre-modification cables from 2,500 hours to 800 hours. However, the operator ceased trading before the investigation and cable modification programme was complete.

Other information

Aileron cable failures on Boeing 737 aircraft

In 1997, the National Transportation Safety Board (NTSB) investigated an event on a Boeing 737 aircraft where an aileron cable broke where it passed over a pulley in the right wing-root, mainwheel well[16]. The investigation found that the cable failed due to a combination of internal and external wear with a metallurgist estimating that over 90% of the cable's total cross-section had been removed by the internal wear. The investigation established that six other similar failures had occurred over a 10-year period.

The NTSB made several recommendations to the FAA and Boeing, which included the provision of advice to aircrew, the introduction of a cable life, and inspection methodology and periodicity. The latter included a Recommendation that:

> *'the inspection should include releasing cable tension to better detect cable wear and wire breakage and establishing a maximum allowable reduction in cable diameter where pulley contact occurs.'*

Inspection procedures were amended to include rubbing a cloth along the length of the cable to catch on broken wires and a requirement to move the handwheel through its full range to expose parts of the cable that are hidden by the pulleys. Instructions for checking cable diameter wear were included as an option but the proposal that the tension be released prior to the cables being inspected was not incorporated.

Unresponsive aileron in-flight

Unresponsive aileron during event flight

During this investigation an issue, unrelated to the cable failure, was identified with the movement of the right aileron in-flight. Data from the FDR showed that shortly after G-FLBE levelled at FL200, the aileron stopped responding to movement of the handwheels (Point A Figure 6). This lasted for about five minutes, with the aileron remaining in an almost fixed position of +5°. During this period, the AP continued to maintain wings level with handwheel positions between 13° CW and 27° CW. The inboard spoilers continued to operate normally during the flight.

As the aircraft started its descent to Exeter, the movement of the aileron suddenly returned to normal (Point B Figure 6). This coincided with the handwheels being moved by the AP from 27° CW to 35° CW as the aircraft rolled out of a left turn.

Footnote

[16] NTSB report SEA97IA219, Boeing 737-3T0, N13331, occurrence date 27 September 1997, https://www.fss.aero/accident-reports/dvdfiles/US/1997-09-27-US.pdf (Accessed 9 April 2020).

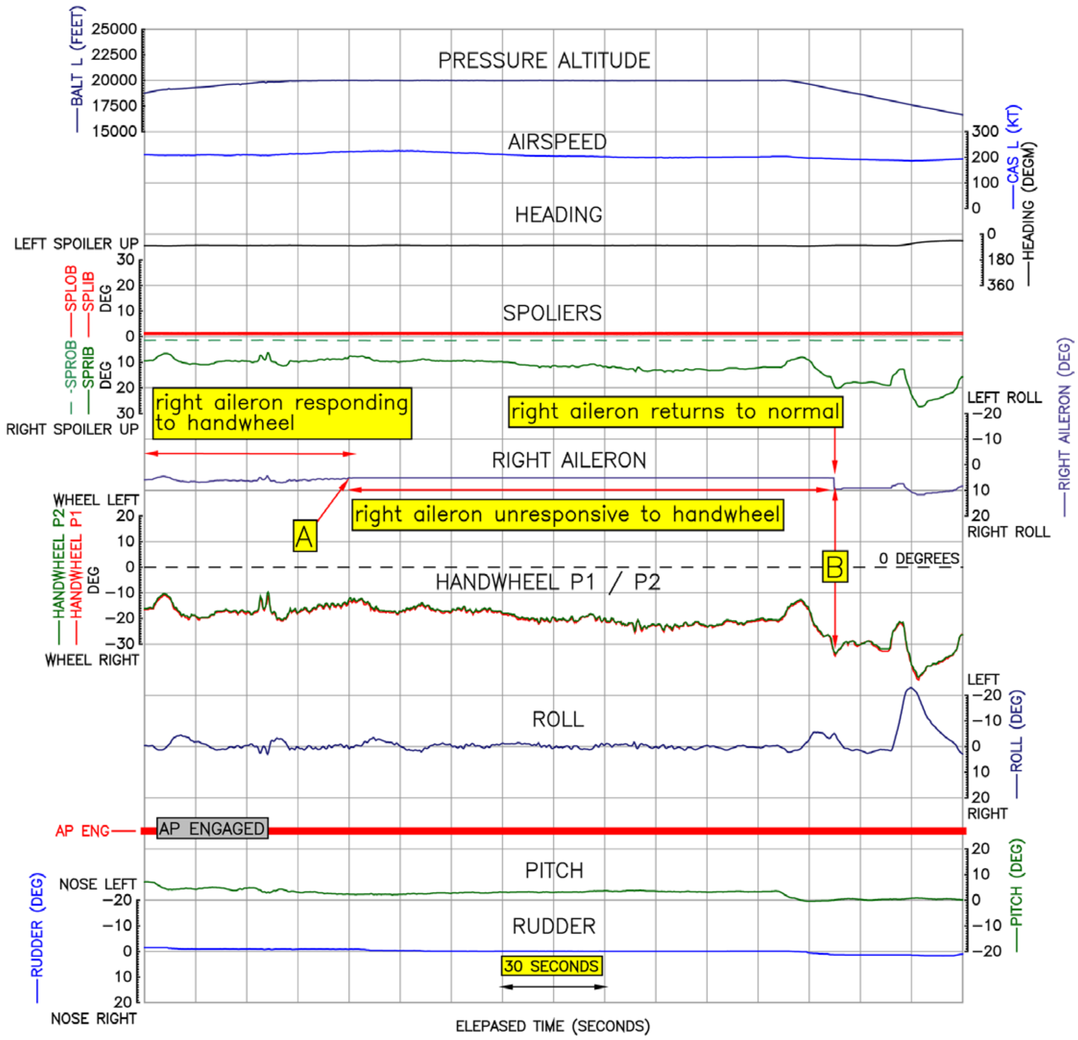


Figure 6

Unresponsive right aileron

Other occurrences of unresponsive ailerons

Analysis of the FDR data from G-FLBE showed that the right aileron had previously stopped responding to the position of the handwheels during 14 of the previous 23 flights. Durations varied from between two and thirty-five minutes.

The aileron typically became unresponsive as the aircraft approached the top of climb or was in the cruise. There was, however, one flight where the aileron was unresponsive during descent from FL100 to FL060. The movement of the aileron always returned to normal prior to the aircraft starting the final approach. Normal operation of the aileron often coincided with movement of the handwheel as the aircraft entered a turn.

During the three flights prior to the incident flight, the right aileron was unresponsive for periods of 25, 35 and 26 minutes respectively. For the flights prior to these three, there was more variation in the duration that the right aileron was unresponsive.

The operator's Flight Data Monitoring department subsequently analysed data from its fleet of DHC-8-400 aircraft to identify if the right aileron was unresponsive on other aircraft. Initially 32 flights from 16 aircraft were reviewed and during half of these the right aileron was unresponsive for periods during flight. The review was extended to 51 aircraft for seven days flying during February 2020 and after the aileron cables had been replaced and tensioned on G-FLBE. The review looked for periods when the right aileron remained unresponsive to handwheel movement for more than 60 seconds. The results were:

- Thirty-six out of fifty-one aircraft had unresponsive ailerons.
- Twelve of the aircraft with an unresponsive aileron had an occurrence rate of 25% or more.
- The fleet leader was G-FLBE with a rate of 64% (21 events during 33 flights).

The operator had scheduled work on G-FLBE to isolate the cause of the unresponsive right aileron but ceased trading prior to this being concluded.

Manufacturer's response

The aircraft manufacturer analysed the FDR data from G-FLBE and offered several reasons as to why the ailerons could become unresponsive:

- Frozen hinge bearing,
- Frozen pulley bearing,
- Deteriorated flap seal and/or aileron hinge seal,
- Low cable tension, or
- Damaged wires snagging on pulleys.

Modelling of the FDR data from one of G-FLBE's flights, before the left aileron cable broke, showed that during a period when the right aileron had been unresponsive, the left aileron had continued to operate normally. This modelling was not applied to the entire flight nor to other previous flights recorded on the FDR.

FDR parameter filtering

Filtering of parameters

During this investigation, the aircraft manufacturer informed the AAIB that filtering was applied to the position of the handwheels, control columns and rudder pedals recorded on the FDR fitted to G-FLBE. The filtering was used to smooth out signal noise using a moving average calculation that was not reversible. This meant that during rapid control movements, the actual position of the controls could not be reliably reconstructed from FDR data. The filters also caused the recorded positions of the control inputs to lag the movement of the control surfaces (which were not filtered) by about 0.5-second. The filtering was in place on all of the operator's fleet of DHC-8-400 aircraft, and other aircraft operating in Europe.

The FDR system fitted to the DHC-8-400 aircraft met the minimum performance standard defined by European Organization for Civil Aviation Equipment (EUROCAE) document

ED- 55[17] dated 1990. This provided requirements for the accuracy of FDR parameters but did not address filtering.

Previous Safety Recommendations

The issue of parameter filtering has previously been addressed by the NTSB and AAIB. Details are in the Appendix to this report and a summary is provided below:

> In 1994, the NTSB issued two Safety Recommendations to the FAA to require that filtering should not be used unless the position of the flight controls can be recovered from the FDR. In 2000, the Safety Recommendations were closed and classified as *'acceptable action'.*
>
> In 1999, the AAIB issued two Safety Recommendations to the CAA, one of which was to alert EUROCAE[18] of the problem. The Safety Recommendations were accepted and guidance on parameter filtering was issued in 2003. The CAA also advised that changes to the JAR would be sought from the JAA[19], but no changes were made to the JAR.
>
> In 2003, the NTSB made three Safety Recommendations regarding the sampling rate and filtering of the position of control surfaces following the in-flight failure of a fin on an Airbus A300-600. In 2010 the FAA amended Federal Aviation Regulations (FAR) to address parameter filtering.
>
> In 2013, the manufacturer of the DHC-8-400 aircraft advised USA operators that because an irreversible filter had been applied to the handwheel, control column and rudder pedals position and force parameters, the FDR installation on these aircraft did not meet the FAR. A SB was subsequently issued in December 2013 to correct this. This SB was not applicable to aircraft registered outside the USA. Neither the CAA nor the EASA required irreversible filters to be removed from DHC-8-400 aircraft operating in the UK or Europe.

International Civil Aviation Organisation guidance on FDR parameter filtering

The International Civil Aviation Organisation (ICAO) sets the Standards and Recommended Practices (SARPs) for Contracting States including the UK. ICAO Annex 6, Part 1 is applicable to Commercial Air Transport operations by aeroplanes, and ICAO Annex 6, Part 3 is applicable to helicopters. Both SARPs specify aspects such as the construction and operation of FDR systems, but neither address the recording of filtered parameters.

Footnote

17 ED-55 Minimum Operational Performance Specification for Flight Data Recorder Systems.

18 EUROCAE is a non-profit organisation that develops specifications for aircraft electronic equipment. The creation and update of these specifications are made by working groups consisting of industry representatives and experts.

19 The Joint Aviation Requirements (JAR) were a set of common European aviation requirements issued by the Joint Aviation Authorities, of which the CAA was a member.

Analysis

Effect of the aileron cable breaking

The failure (break) of the aileron control cable affected the position of the left aileron, which caused the aircraft to roll to the left. This was corrected by the pilot and AP providing a correcting input which displaced the handwheel from its normal neutral position. The amount of displacement varied at different stages of the flight due to a combination of the aircraft speed and roll control being assisted by the outboard spoiler: the spoiler becomes active below 165 kt.

The manufacturer was aware of three other events where a broken aileron cable was detected in-flight. As part of this investigation the Regulator and Manufacturer reviewed the risk resulting from the failure of an aileron cable and confirmed that such a failure had a Severity Classification of Minor.

Pilots response to the event

The pilots noticed the effect of the cable break shortly after departing Newquay where the wind was close to the aircraft's crosswind limits of 32 kt. They reviewed the QRH but did not consider any of the checklists to be relevant. Therefore, they carried out a threat assessment and mitigated the risk of flying with a reduced handwheel range of movement by diverting to Exeter where the crosswind was not as strong. The aircraft made an uneventful landing.

An aileron cable breaking in level flight would initially cause an uncommanded roll and the most relevant QRH non-normal checklist was '*Roll Control Malfunction*', which has the precondition '*Aircraft rolls with no control wheel* [handwheel] *input'*. However, the pilots did not recognise the relevance of this checklist, possibly because the AP was engaged and would have automatically countered the uncommanded roll to the left.

Cable failure

The lower left aileron cable failed due to a combination of internal and external wear. Following the failure, the tension in the upper cable would have caused the aileron to deflect upwards inducing a roll to the left. From the FDR data, it was established that the cable failed between the aircraft landing at Newquay and during the subsequent takeoff.

The landing at Newquay, which was close to the limit for classification as a heavy landing, would not have caused a serviceable cable to fail; however, the aileron cable was worn and its load carrying capability would have been reduced. It is, therefore, possible that the cable failed during the landing.

If the failure had occurred during the landing, then the pilot might have noticed that the aileron was at an unusual angle[20] during the pre-flight external inspection. However, the inspection was carried out at night, in gusty, showery conditions which might make it more difficult to notice the unusual angle of the aileron.

Footnote

20 The position of the gust locks would not affect the movement of the aileron following the failure of the cable.

The failure of the aileron cable would have had no significant effect on the force required to operate the handwheels, and the aileron position is not displayed in the cockpit. Consequently, the pilots could not have detected the failure if it had occurred after the external inspection had been completed.

Cable wear and possible causes

The aileron and spoiler cables are known to be susceptible to wear in the areas where they are redirected by pulleys to accommodate the change in the wing dihedral. The manufacturer published their first advice to operators in 2004 and modified cables with a polymer coating were introduced in 2015. The modification was not mandatory and while the operator was in the process of modifying their fleet, the new cables had not been fitted to G-FLBE.

The manufacturer identified low tension, vibration and contamination as the main causal factors for wear in control cables.

Cable tension. The aileron cable was found to be below the minimum allowable tension when it was last checked 1,100 hours before the failure occurred. The cable was re-tensioned, and the aircraft released to service.

If the cable tension is too low, then the friction between the pulley and cable may not be sufficient to overcome the breakout force of the bearing fitted to the pulley with the result that the pulley does not rotate as the cable moves. The resulting sliding contact can cause wear in both the cable and pulley.

Following the cable failure, the pulley on G-FLBE was found to rotate freely. The wear around the pulley's circumference was relatively even and there was no evidence of slippage having occurred. Therefore, low cable tension resulting in slippage between the pulley and cable was not considered to have been a causal factor in the failure of the cable. However, the low tension identified 1,100 hours previously might have been an indication of broken wires inside the cable.

Vibration. The aileron and spoiler cables are routed along the wing rear spar just outboard of the engines. Vibration from the engines could cause increased cable wear if the tension is low, by allowing the individual strands, and wires, to move against each other. The wear resulting from vibration would accumulate at a greater rate in cables that are contaminated with debris. However, the investigation could not establish if vibration from the engines was a causal factor.

The FAA has stated that polymer coated cables should be more tolerant of wear resulting from vibration.

Contamination. The area of the rear wing spars where the aileron and spoiler cables run were found to be heavily contaminated on G-FLBE when it was examined after the failure. The failed cable, and two other cables that were removed from the operator's aircraft as part of this investigation, were examined and exhibited evidence of wear with excessive amounts of grime, grease and debris both on the cable and imbedded between the strands and wires.

It is known that accumulation of grease and debris on a control cable can cause accelerated wear and it is probable that this was a factor in the aileron cable failing on G-FLBE.

Inspection frequency

Pre-modification cables are required to be wiped clean and visually inspected every 2,500 hours. However, the aileron cable on G-FLBE failed 1,400 hours after its last inspection; the operator also identified 18 cables on their other aircraft, which were not due to be examined, with damage that exceeded the allowable limits. This suggests that the inspection frequency may be inadequate for aircraft whose operations result in a heavy accumulation of dirt along the rear wing spars.

The evidence is that the polymer sleeves fitted to the modified aileron cables reduce the rate of in-service wear as they prevent the ingress of debris into the cable.

Inspection procedure

The effectiveness of the visual inspection relies on the maintainer identifying broken wires, or wear, and assessing the damage against the acceptable limits in the AMM. However, the cable construction means that only 42 of the 133 individual wires are visible and of these 42 wires, only one side of each wire is visible.

While visual inspections are used successfully across the industry as a method of detecting damage in cables, it has an inherent limitation in that it cannot identify internal damage. The probability of identifying broken internal wires can be increased by releasing the cable tension and manipulating the cable, but this is not a requirement of the AMM. The inspection procedure suggests the use of a torch and mirror, where appropriate, and required the handwheel to be moved '*if necessary*' to expose areas of the cable that were normally hidden from view. However, it is not possible to inspect the susceptible sections of the aileron cable without repositioning it by moving the handwheel through its full range of movement.

In order to increase the probability of detecting damage and preventing the failure of control cables that run along the wing rear spar, the manufacturer advised that they had initiated the following safety actions, which should be completed by the end of 2020:

Safety Action

The aircraft manufacturer reviewed the periodic cable inspection procedure and advised that they would amend the procedure to increase the likelihood of identifying cable damage. They also stated that they would issue an All Operators Message to highlight this serious incident and the changes to the inspection procedure.

Unresponsive aileron movement in-flight

The investigation found that the right aileron recorded on the FDR on the operator's DHC-8-400 aircraft would routinely stop responding to handwheel movements during flight. Most events occurred when the aircraft was near the top of climb or in the cruise, and the movement would return before the aircraft landed. The spoilers continued to operate normally throughout the flights.

The aircraft manufacturer modelled the FDR data from one of G-FLBE's flights before the cable had broken. This indicated that during the period when the right aileron had been unresponsive, the left aileron had continued to operate normally. This modelling was not applied to any other flights.

The left and right aileron system share a common design; therefore, the left aileron could equally be susceptible to becoming unresponsive. The aircraft manufacturer advised that on G-FLBE there could be several reasons for the aileron becoming unresponsive including frozen hinge bearing; frozen pulley bearing; deteriorated flap seal and/or aileron hinge seal; low cable tension or damaged wires snagging on pulleys. FDR data showed that during flight the unresponsive right aileron would suddenly return to normal operation. This typically occurred when a left or right turn was initiated.

The low cable tension would have resulted in a more gradual movement of the aileron, rather than a sudden movement as it returned to normal. Moreover, after the cables were replaced and correctly tensioned on G-FLBE the problem remained. Therefore, the right aileron becoming unresponsive was likely to have been caused by a restriction, or a combination of restrictions. There was no evidence of the AP disconnecting during periods when the right aileron was unresponsive or when it returned to normal; therefore, the force to overcome the restriction/s did not exceed 17.5 lb at the handwheel.

The operator was in the process of investigating the cause of the unresponsive aileron on G-FLBE when they ceased trading. Consequently, the cause was not identified.

In order to understand if other operators of DHC-8-400 aircraft had also experienced unresponsive ailerons, the manufacturer advised that they had initiated the following safety action:

Safety Action

The aircraft manufacturer advised that it would provide literature to operators to monitor for unresponsive ailerons using their Flight Data Monitoring Programmes.

Although the aircraft manufacturer has initiated safety action to monitor for unresponsive ailerons, the specific causes and rectification actions have yet to be determined. It is important that accident investigators and operators fully understand why the aileron becomes unresponsive, its effect on aircraft performance and what rectification action is required. Therefore, the following Safety Recommendation is made:

Safety Recommendation 2020-024:

It is recommended that Transport Canada require De Havilland Canada to determine why the aileron control surfaces on the DHC-8-400 series of aircraft can become unresponsive to handwheel movements and ensure that the findings and any rectification action is promulgated to operators.

FDR parameter filtering

On the DHC-8-400 aircraft operating in Europe, irreversible filters are applied to the data from sensors on the handwheels, control columns and rudder pedal positions and forces recorded by the FDR. Consequently, the actual sensor position of these parameters may not be reliably reconstructed during rapid movements of the controls. In 2014, the FAA required irreversible filters to be removed from the DHC-8-400 aircraft registered in the USA; however, no similar requirement was made for DHC-8-400 aircraft registered in Europe[21].

It is essential during safety investigations to have access to FDR data which can be used to reconstruct an accurate and unambiguous time history of each parameter's activity, which the use of irreversible filters precludes. Therefore, the following Safety Recommendation is made to the EASA:

Safety Recommendation 2020-025:

It is recommended that the European Union Aviation Safety Agency require that the flight data recorder system fitted to DHC-8-400 series of aircraft registered in Europe record unfiltered data for the parameters representing primary flight control input positions and input forces, so that their original sensor signal values can be reliably established.

To ensure National Aviation Authorities adopt a common international standard on the use of filters applied to the parameters recorded by the FDR, the following Safety Recommendation is made to the ICAO:

Safety Recommendation 2020-026:

It is recommended that the International Civil Aviation Organisation provide guidance on the recording of filtered parameters by the flight data recorder system. The guidance should address as a minimum:

1. Definitions for filtered and unfiltered parameters.
2. Parameters on the FDR for which filtering is not permitted.
3. The need to be able to reconstruct the original sensor signal values from filtered data recorded during extremely dynamic conditions and that the information to achieve this is a permanent part of the aircraft specific FDR system documentation package.

Footnote

21 Parameter filtering for DHC-8-400 aircraft registered in the USA was removed by SB 84-31-65 that fitted a modified Flight Data Signal Conditioning Unit (FSCU). This FSCU would also remove parameter filtering from DHC-8-400 aircraft registered in Europe.

Conclusion

The most probable reason for the aileron cable breaking was that its strength had reduced as a result of wear leading to the failure of individual wires within the cable. The cable failed where it passed over a pulley on the rear wing spar where dirt accumulates which can penetrate into the strands and form an abrasive compound. This can accelerate the normal rate of cable wear. Post-modification cables are available which have a sleeve fitted over the susceptible section to prevent the ingress of dirt. The investigation established that the inspection procedure in the AMM would not have detected the damage to individual wires that run inside the cable.

The unresponsive right aileron on G-FLBE was not causal to this serious incident. As the operator ceased trading before they could establish the cause on G-FLBE, and other aircraft in their fleet, further investigation is required to determine if there is a wider safety issue.

Filters applied to some of the flight control parameters recorded on the FDR can affect the reconstruction of the rapid movement of the controls. Such filters are not permitted to be installed on the DHC-8-400 aircraft registered in the USA, but there is no similar requirement on aircraft registered in Europe or the UK. While this did not affect this investigation, this could affect other safety investigations.

Safety actions/Recommendations

Safety Recommendations

The following Safety Recommendations were made:

Safety Recommendation 2020-024:

It is recommended that Transport Canada require De Havilland Canada to determine why the aileron control surfaces on the DHC-8-400 series of aircraft can become unresponsive to handwheel movements and ensure that the findings and any rectification action is promulgated to operators.

Safety Recommendation 2020-025:

It is recommended that the European Union Aviation Safety Agency require that the flight data recorder system fitted to DHC-8-400 series of aircraft registered in the United Kingdom record unfiltered data for the parameters representing primary flight control input positions and input forces, so that their original sensor signal values can be reliably established.

Safety Recommendation 2020-026:

It is recommended that the International Civil Aviation Organisation provide guidance on the recording of filtered parameters by the flight data recorder system. The guidance should address as a minimum:

1. Definitions for filtered and unfiltered parameters.
2. Parameters on the FDR for which filtering is not permitted.
3. The need to be able to reconstruct the original sensor signal values from filtered data recorded during extremely dynamic conditions and that the information to achieve this is a permanent part of the aircraft specific FDR system documentation package.

Appendix

In 1994 the NTSB made Safety Recommendation A-94-120 and A-94-121 to the FAA to address parameter filtering. This followed an NTSB investigation where it had been demonstrated that it was not possible to determine the actual position of filtered control surfaces recorded by the FDR system fitted to Boeing 757 and 767 aircraft:

> *'**NTSB Recommendation A-94-120** The NTSB recommends that the federal aviation administration: require design modification to the Boeing 757/767 so that flight control position data to the DFDR is accurate and not filtered by the EICAS. The sample rate should also be increased to an appropriate value'.*

> *'**NTSB Recommendation A-94-121** The NTSB recommends that the federal aviation administration: review other airplane designs to ensure that flight control position data to the DFDR are accurately recorded and that flight control position data filtered by systems such as EICAS are not substituted for accurate data'.*

The FAA subsequently required that the filtering was to be removed from Boeing 757 and 767 aircraft by May 2000. The FAA also reviewed other aeroplane designs[22] and in 1999 it published Advisory Circular (AC)[23] 20-141[24]. This provided guidance on FDR parameter filtering and recommended that no significant[25] differences should exist between the actual control surface position and the signal recorded on the FDR during both static and dynamic conditions[26]. The FAA also stated that it would ensure that USA operators would no longer record filtered parameters on the FDR.

In 2000, the NTSB classified Recommendation A-94-120 and A-94-121 as '*closed – acceptable action*' in lieu of assurances from the FAA that filtered FDR data would be precluded.

Footnote

[22] Aerospatiale, CASA, Cessna, Grumman, Gulfstream, Israel Aircraft Industries, Lockheed, and SAAB.
[23] An AC is not mandatory or a regulation, but can provide information on an acceptable means of compliance when applying for certification.
[24] AC 20-141 was superseded by AC 20-141B in 2010. This contained additional guidance information on parameter filtering.
[25] The FAA defined no significant difference as 'any differences between the data recorded under static conditions and the data recorded under dynamic conditions should be less than the correlation coefficient derived using static parameter values.
[26] Defined by the FAA as when undergoing change at the maximum rate expected when operating the aircraft in accordance with the flight manual.

In 1999, the AAIB investigated a landing accident involving a Boeing 767 aircraft, registration N373AA. The filtering of the flight control parameters was still in place on this aircraft. The AAIB subsequently made the following Safety Recommendations to the CAA to address the use of parameter filtering for aircraft registered in the UK and Europe, and to amend international specifications applicable to FDR systems:

AAIB Recommendation 99-43[27]

The Civil Aviation Authority initiate action to change Joint Aviation requirements in JAR OPS 1.715 (d), 1.720 (d) and 1.725 (d), which currently read:

> "Data must be obtained from aircraft sources which enable accurate correlation with information displayed to the flight crew"

and which should be rewritten to read:

> “Ensure that accurate data is recorded on the DFDR and that data filtered by systems for displays to the flight crew is not substituted for accurate data"

Note: Changes to 1.720 and 1.725 are required to cater for the situation where modern, novel and/or unique avionics are fitted into old airframes. The revised paragraph should be added to 1.715 to cater for DFDR designs in new aircraft.

AAIB Recommendation 99-44

The Civil Aviation Authority alert EUROCAE WG50 to the problems posed by filtered data so as to ensure that the latest revision of ED55 contains suitable advice on the need to avoid substituting filtered data for accurate data in recording systems.

Safety Recommendations 99-43 and 99-44 were accepted by the CAA in 2000, and specification ED-55 was subsequently superseded by ED-112[28] in 2003. This incorporated the following guidance on parameter filtering; the same information was included in ED-112A which superseded ED-112 in 2013:

Parameter filtering ED112 and ED-112A - section II-A.9

> *‘Data shall be obtained from sources within the aircraft, which provide the most accurate and reliable information under both static and dynamic conditions. The use of filtered data should be avoided but may be used if it can be demonstrated that the accuracy requirements are maintained for values recorded during dynamic conditions equivalent to the operational limits of the system being measured.’ The actual sensor value shall be retrievable from the filtered data*

Footnote

27 JAR OPS 1.715 was applicable to aeroplane’s first issued with an individual certificate of airworthiness (C of A) on or after 1 April 1998, JAR OPS 1.720 was applicable to aeroplane’s first issued with an individual C of A on or after 1 June 1990 up to and including 31 March 1998 which had a maximum certificated takeoff mass over 5 700 kg.JAR OPS 1.725 was applicable to any turbine engine aeroplane first issued with an individual C of A, before 1 June 1990 which has a maximum certificated takeoff mass over 5,700 kg.

28 Minimum Operational Performance Specification for Crash-Protected Airborne Recording Systems

by any technically cognizant individual in an 8 hours period using existing, and easily understood instructions that specify commonly available tools and techniques.'

ED-112 and ED-112A also stated that filtering shall be avoided for parameters representing primary flight control positions and forces, position of the power levers and positions of primary flight surfaces, unless it can be demonstrated that:

'The recorded values meet the accuracy requirements in extremely dynamic conditions, in spite of the filtering; or, original sensor signal values can be reconstructed from filtered data recorded in extremely dynamic conditions, and this reconstructed values meet the accuracy requirements (see tables II-A.1 and II-A.2). The original sensor values shall be retrievable by applying a unique algorithm to the filtered values. This algorithm shall be a permanent part of the aircraft specific FDR system documentation package.'

The CAA response to AAIB Recommendation 99-43 stated *'Action to initiate changes to the requirements in JAR OPS 1.715 (d), 1.720 (d) and 1.725 (d) in line with those set out in this Recommendation has already been taken with the Joint Aviation Authorities (JAA) Flight Recorder Study Group.'* However; no changes were subsequently made to JAR OPS 1.715 (d), 1.720 (d) or 1.725 (d). It is not known why the changes were not made.

The JAA JAR-OPS 1 requirements for commercial air transport aeroplanes were replaced by EU-OPS in 2008: this was subsequently superseded in 2012 by Commission Regulation (EU) No 965/2012 EASA Air Ops regulations. This required that the actual position of filtered parameters should be recoverable (as defined in ED-112A) for fixed-wing aircraft[29] and helicopters fitted with an FDR, and first issued with an individual C of A after 01 January 2016. However, this requirement was not applicable to fixed-wing aircraft or helicopters first issued with a C of A before 1 January 2016; this included G-FLBE and the operator's fleet of DHC-8-400 aircraft.

In November 2003, the NTSB notified the FAA that its investigation[30] into the in-flight separation of the vertical fin and rudder of an Airbus A300-600 had been hampered by the low sampling rate and filtering of the rudder control surface recorded by the FDR. The NTSB subsequently made three Safety Recommendations (A-03-48, A-03-49 and A-0-50) to the FAA. These addressed accuracy, sampling rate and filtering of parameters, so that an unambiguous time history of parameter activity could be obtained from the FDR.

In 2010, the FAA responded to the recommendations by adding new rules to 14 CFR[31] Part 121, 125 and 135[32] as FARs 121.346, 125.228 and 135.156. This required manufacturers

Footnote

[29] EASA define aeroplane as a fixed wing aircraft. This report uses the term aircraft instead of aeroplane.

[30] https://www.ntsb.gov/investigations/AccidentReports/Reports/AAR0404.pdf [Accessed 1 OCtober 2020].

[31] Title 14 of the Code of Federal Regulations.

[32] Part 121 - operating requirements: domestic, flag, and supplemental operations,
Part 125 - certification and operations: airplanes having a seating capacity of 20 or more passengers or a maximum payload capacity of 6,000 pounds or more,
Part 135 - operating requirements: commuter and on demand operations.

to either provide information that enabled the actual sensor positions to be accurately reconstructed from filtered parameters on the FDR, or the filters were to be removed. This was to be completed by 1 April 2014, and was applicable to the following FDR parameters:

- Pitch control, lateral control and rudder control inputs.
- Primary pitch, lateral and yaw control surface positions.
- Throttle/power lever positions.
- All flight control input forces (handwheel, column and rudder pedals).

In September 2013 the manufacturer of the DHC-8-400 advised USA operators[33] that the FDR system did not meet the requirements of FAR 121.346. This was because an irreversible filter was applied to the handwheel, control column and rudder pedal positions and forces[34]. The FDR system fitted to DHC-8-100, -200 and -300 aircraft was not affected. In December 2013 the aircraft manufacturer issued SB 84-31-65. This fitted a Flight Data Signal Conditioning Unit (FSCU)[35] that removed the filtering. SB 84-31-65 was not applicable to DHC-8-400 aircraft registered outside the USA.

Published: 15 October 2020.

Footnote

[33] Service Letter (SL) DH8-400-SL-31-007B refers.
[34] The input force parameters are only required to be recorded for aircraft registered in Europe that were first issued with a C of A on or after 1 January 2016 and in the USA for all turbine-engine-powered transport category airplanes manufactured after 19 August 2002.
[35] Honeywell Avionics manufactured FSCU, part number 1152862-5.

ACCIDENT

Aircraft Type and Registration:	Colibri MB2, G-BUDW
No & Type of Engines:	1 Volkswagen 1834cc piston engine
Year of Manufacture:	1992 (Serial no: PFA 043-10644)
Date & Time (UTC):	15 December 2019 between 1228 and 1328 hrs
Location:	Northfield Farm, Spilsby, Lincolnshire
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - 1 (Fatal) Passengers - N/A
Nature of Damage:	Aircraft destroyed
Commander's Licence:	Private Pilot's Licence
Commander's Age:	55 years
Commander's Flying Experience:	1,300 hours (of which 221 were on type) Last 90 days - 11 hours Last 28 days - 1 hour
Information Source:	AAIB Field Investigation

Synopsis

The pilot, who owned G-BUDW, was planning a short flight to test a modification to the aircraft's fuel system. As the aircraft took off a witness heard the engine running roughly before it disappeared from view. The accident site was found approximately one hour later to the north of the runway. It is likely the pilot had attempted to fly a circuit to land back at the airfield.

The investigation found the engine was in poor condition with several defects including a crack in the cylinder head, a split in the inlet manifold joint and deposits on the valve seats. Any of these on their own or a combination of these, could explain the rough running.

The report highlights the guidance issued by the LAA regarding pilot maintenance, on-condition engine monitoring, development of a maintenance schedule and the requirements relating to approval of modifications.

History of the flight

The owner of G-BUDW kept his aircraft at a small farm airstrip near Mavis Enderby in Lincolnshire. In the months leading up to the accident it was reported that G-BUDW had been experiencing a rough running engine and loss of engine power in flight. In April 2019, he had an engine failure and landed in a field. He was able to fix the problem and took off again 40 minutes later. It was reported that he had aborted several flights in recent months and returned to the airfield due to engine problems. The owner had tried several solutions to resolve the engine problems including fitting an additional electric fuel pump. On the day before the accident the owner had modified the fuel system to change the arrangement of the electrical and mechanical fuel pumps.

On the day of the accident, it was reported that the owner intended to undertake a short flight to test the modified fuel system. An old grain shed, at one end of the runway, was used to store G-BUDW and three other aircraft. When the owner of G-BUDW arrived at the airfield, another pilot was working on their aircraft. The other pilot was busy with his own aircraft so, other than exchanging some pleasantries, they did not speak. However, the other pilot was aware of G-BUDW's owner preparing his aircraft.

The other pilot later heard the aircraft start and reported that "the engine sounded fine", a few minutes later he saw the aircraft taxi away. When he heard G-BUDW start its takeoff, he walked out of the hangar to watch and recalled it was 1232 hrs. He reported that when he saw the aircraft come over the crest of the runway it was at about 5 – 10 ft and the engine sounded "good". He then heard the engine go much quieter "as if it had been altered to tick over" and was aware the aircraft was no longer climbing normally. He heard the engine "get loud again then hesitate and get quiet again" and described the engine as "fizzing and popping". The aircraft passed directly over his head, clearing the shed roof by 20 – 30 ft. As the aircraft went out of sight, he could no longer hear the engine and assumed the pilot would be attempting a forced landing in a field. He ran around the shed but could not see the aircraft.

He returned to his car and started a search of the surrounding area but was unable to locate the aircraft. At 1252 hrs, he called the pilot of one of the other aircraft in the hangar and asked if he could come to the airfield and use his aircraft to search the area. At 1315 hrs, the other pilot arrived, prepared his aircraft for flight and started to taxi to the far end of the airfield for takeoff. As he taxied over the crest of the runway, he saw the wreckage of G-BUDW in the field to the north of the runway. They alerted the emergency services and attempted to revive the owner but there were no signs of life. The call to the emergency services was made at 1328 hrs.

The police, paramedics and air ambulance attended but the owner was declared deceased at the scene.

Two other people witnessed parts of the aircraft's flight. One witness, who was to the south of the airfield (Figure 1 - Witness A), saw the aircraft track east to west then saw it turn to the north. He reported the engine sounding rough, describing it as "stuttering a bit" and making a "putt, putt, putt" sound. A second witness, to the north-east (Figure 1 - Witness B) of the airfield reported hearing the aircraft starting its takeoff. He reported that the aircraft sounded "lovely, smooth and sweet".

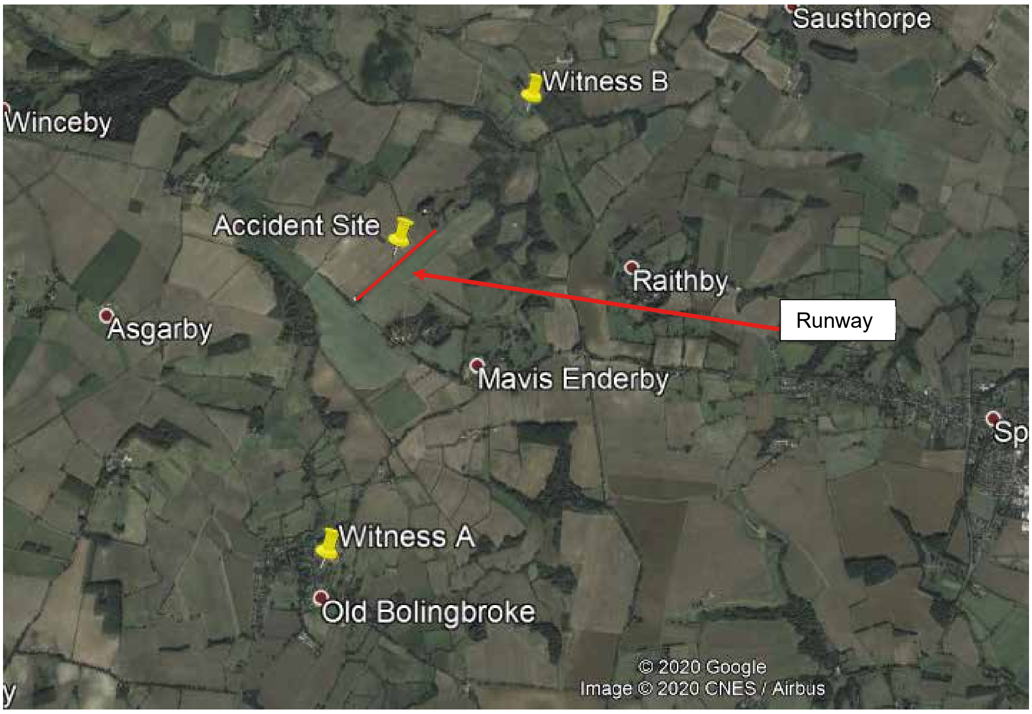


Figure 1
Location of witnesses

Several other people in the surrounding area reported hearing aircraft with engine problems, but the times and distance from the airfield suggest these were unlikely to be the accident aircraft.

Accident site

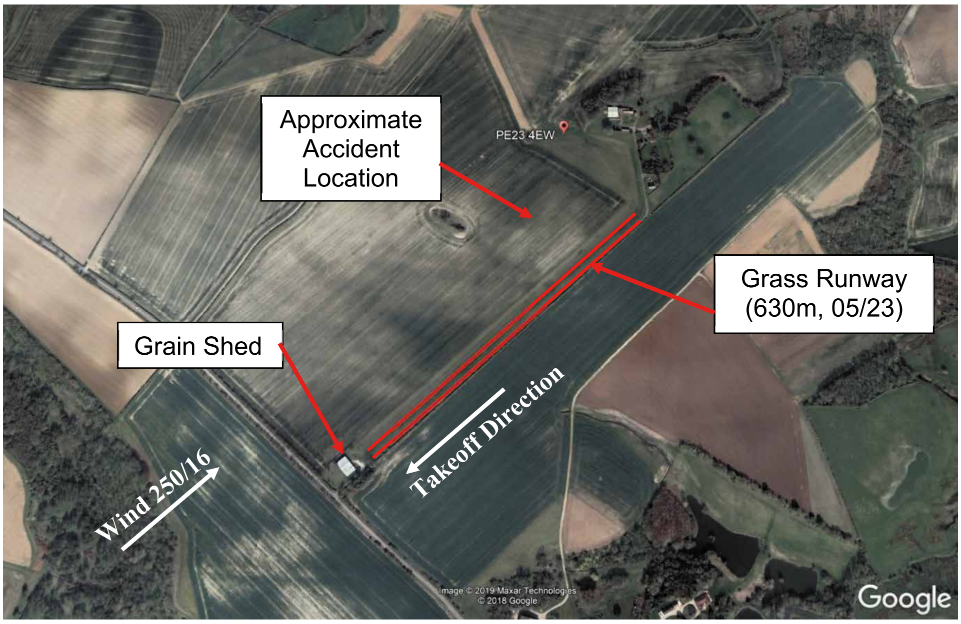


Figure 2
Farm strip showing the accident site location

The aircraft wreckage was discovered approximately 50 m to the north of the grass runway and from the ground marks it was apparent that the aircraft was heading in a south south-westerly direction. The accident site was hidden from the grain shed due to the ground rising and falling around the midpoint of the runway.

The right wing and landing gear had detached from the aircraft during the impact sequence. Ground markings showed that the right wingtip and wheel were the first points to contact the soft, sticky, clay soil (Figure 3). Both blades of the wooden propeller had detached and were found, embedded in the ground where the engine had first struck the ground. The engine was detached from the fuselage. The fuselage was relatively intact and had come to rest 2-3 m from the right wing, adjacent to the left wing, which had also detached. The cockpit area had been severely disrupted. The fuel tank had been moved away from the aircraft by the first responders to minimise the risk of fire as they stated there was still fuel in the tank. No fuel remained in the tank when it was recovered by the AAIB. The wreckage was removed and taken to the AAIB facilities for further examination.

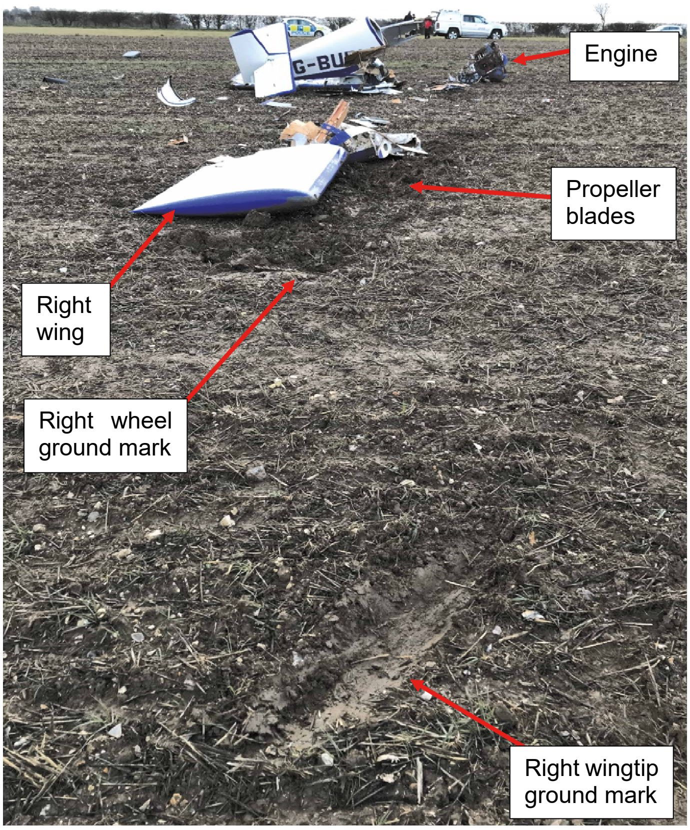


Figure 3

Accident site with ground marks

Recorded information

Radar

No radar recordings existed for the accident flight suggesting that the aircraft was flying at a height of no more than 400 ft agl to be below radar coverage for that area.

GPS devices

An Airbox Aware 5 GPS device was recovered from the accident site which had been active during the flight; however, the file that was downloaded from the device was corrupt and no data for the flight was recovered.

A handheld Yaseu radio with an integrated GPS receiver and recording capability was also recovered from the accident site. However, on examination, no recording was found for the flight because the recording function was in the default OFF position.

Radio transmissions

The aircraft's handheld radio was found tuned to a frequency of 135.465 MHz. The local airfield frequency was 135.480 MHz. The radio's frequency could be changed easily with a little touch on the rotary control knob. It is, therefore, likely that the radio was tuned to the local airfield frequency prior to the accident and that the frequency was knocked slightly during the accident sequence. Transmissions on this frequency are not recorded.

No record was found of any radio transmissions from the aircraft on any other frequency used in the surrounding area.

Aircraft information

The Colibri MB2 aircraft is a homebuilt single seat light aircraft with fixed landing gear, constructed predominantly from spruce and plywood and is operated under a Permit to Fly issued by the LAA. A set of construction drawings for the aircraft was obtained by the AAIB, however these only give construction details for the airframe structure and some other key components such as the flying controls. There were no drawings for the electrical or fuel systems.

G-BUDW was built in 1992 and the original owner and builder flew the aircraft until 2000 when the aircraft was damaged during a forced landing on Taunton Racecourse[1]. Following the accident, the airframe was repaired, and the engine was rebuilt with its capacity increased from 1600 cc to 1834 cc. Once airworthy it was sold, and the new owner converted the ignition system from magnetos to a Leburg electronic ignition system.

The current owner purchased the aircraft in 2007 and flew it regularly. He undertook the maintenance of the aircraft himself, but no evidence of a maintenance programme was found. The aircraft's annual inspection was carried out by a local LAA inspector, as required to maintain the Permit to Fly. Since the engine had been rebuilt, 605 hours of running time had been logged.

Fuel system

The fuel tank was positioned behind the engine bulkhead and was the only fuel system component included in the construction drawings. The outlet from the tank was connected

Footnote

1 https://www.gov.uk/aaib-reports/colibri-mb2-g-budw-12-august-2000 (accessed 4 June 2020).

to a filter / drain assembly attached to the bulkhead and fuel was fed to a Minnow Fish carburettor, positioned on top of the engine, by the fuel pumps. Non-return valves were fitted between the pumps and the carburettor inlet. The air intake to the carburettor was unfiltered and was fitted with a manually operated, carburettor heating system on the exhaust silencer. The intake manifold split the fuel air mixture to both cylinder heads and had flexible joints to allow for alignment and vibration (Figure 4).

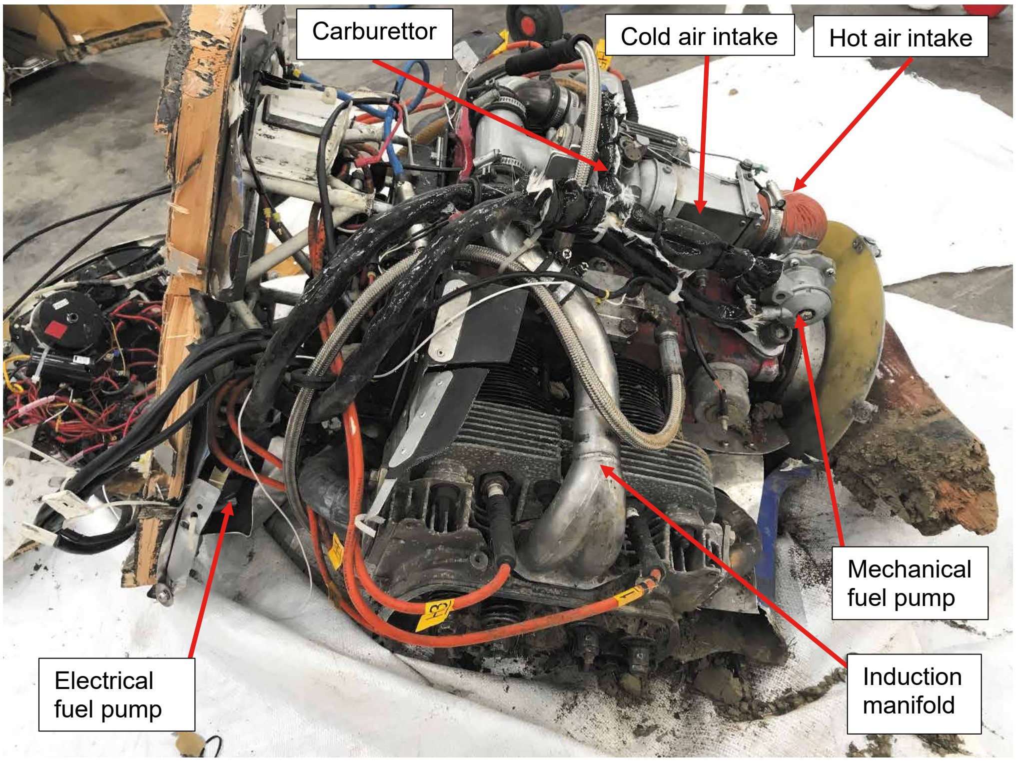


Figure 4
Engine at AAIB facilities

Aircraft examination

The aircraft wreckage was laid out at the AAIB facilities and it was confirmed that there was no evidence of a pre-accident defect or restriction of the flying controls. All the damage found was consistent with the accident. The ignition and fuel systems were removed from the engine, along with the propeller and exhaust system to facilitate a detailed inspection. No anomalies were found during their removal.

Ignition system

The ignition system was sent to a specialist company for testing. It was noted that the coil packs were not the normal type used with the system, but the system functioned correctly. It is probable that these non-standard coil packs were used as this was the prototype installation of the Leburg system and there are no entries in the maintenance logbooks related to their replacement.

Fuel system

The fuel system was removed from the engine and each component individually examined. The copper pipe from the fuel tank to the filter bowl had sheared by twisting, which most likely happened during impact. The rest of the fuel pipes were new fabric-reinforced rubber pipes retained by band clamps and lagged with a fire resistant fibre glass and silicon blanket. This material was wrapped and then held in place by cable ties. The unions (T-pieces, component connectors, etc.) were of a variety of diameters with some push fit, others threaded. Some joints used PTFE tape to aid sealing however this is not recommended because of the risk of slivers of the tape cut by the threads, causing blockages in the fuel system.

The fuel filter bowl contained a small quantity of fine particles and some residual fuel. The filter element was in good condition. The outlet of the filter bowl was connected to a T-piece from which one pipe was connected to the engine driven mechanical fuel pump and the other to an additional electrical fuel pump. The electrical fuel pump was fitted to the bulkhead and could be switched on from a switch on the instrument panel.

A non-return valve was fitted into the outlet pipe from each pump to ensure fuel flow to the carburettor. The electrical fuel pump[2] was a Facet Cube 40106 solid state 12v fuel pump (Figure 5). The manufacturer's datasheet states it is compatible with '*gasoline, diesel, biodiesel, blended alcohol fuels and fuel additives*' and is capable of 32 US Gallons per hour and between 4-7 psi. The manufacturer's data sheet also states that it is not intended for aircraft use however this is probably due to certification requirements rather than its functionality.

Figure 5

Additional electrical fuel pump

There are a wide variety of pump capacities available and there was no evidence that any calculations had been made to size the pump. If the owner had applied to the LAA for a modification he would have been required to present a rationale for the choice of pump. The pump was tested and operated normally.

Footnote

2 https://www.facet-purolator.com/cube/ (accessed 5 June 2020).

The mechanical fuel pump was driven by an auxiliary engine shaft and quill drive. It was a diaphragm pump and records show that the diaphragm and springs were replaced in August 2018. The pump and the fuel priming system functioned correctly and there was a small quantity of fuel remaining in the pump. An internal filter mesh had a small tear (Figure 6 left), it is thought probable that this happened during removal of the mesh when the pump was overhauled. The drive components were examined and found to be worn (Figure 6 lower) to the extent that part of the pump had clashed with the housing (Figure 6 right). This would have limited the volume of fuel pumped on each stroke.

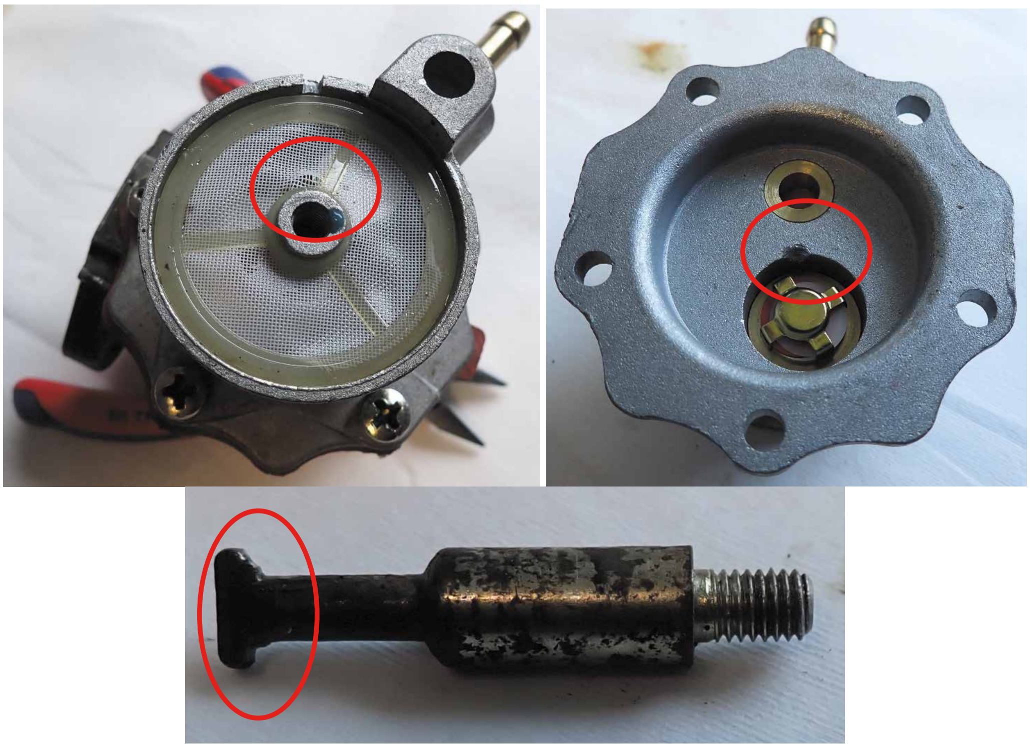


Figure 6

Mechanical fuel pump –
Filter damage, housing damage and drive component wear

Fuel samples

Three metal cannisters of fuel were recovered from the hangar where the aircraft was kept and tested by a fuel laboratory. The laboratory confirmed that the fuel was consistent with Mogas and met the relevant specification[3]. There are many entries in the aircraft logbooks referring to the use of Avgas and so it is likely that the engine was run on both fuel types and mixtures of Avgas and Mogas of varying proportions.

Induction system

The carb heat flap valve and carburettor were examined with no faults found however, there was evidence of small dirt particles in the valve, carburettor venturi and butterfly valve. The

Footnote

[3] BS EN 228:2012+A1:2017 Automotive fuels. Unleaded petrol. Requirements and test methods.

level and size of the particles was consistent with normal operation without an air filter. It was noted that the external surface of a flexible joint in the inlet manifold to the left cylinder head was cracked. Upon closer examination it was found that the crack went all the way through and was approximately 10 mm in length (Figure 7). This crack would have resulted in air entering the system 'leaning' the fuel air mixture. When the interfaces between the inlet manifolds and the engine cylinder heads were disassembled it was found that, in addition to the metal gasket, there was large amounts of silicone instant gasket material. It was not possible to determine whether the metal gasket alone would have provided a suitable seal. No leak paths could be identified.

Figure 7
Inlet manifold flexible joint

Engine

An external inspection of the engine (Figure 8) revealed that the right side had struck the ground, the right rocker cover was missing and the two push rod guide tubes for cylinder 1 were crushed. The rocker cover was found on the accident site and, although covered with soil, was not visibly damaged. The left rocker cover and rocker assembly were removed, and it was noted that the thread on one of the rocker attachment studs differed from the other three suggesting it had been replaced. Furthermore, the nut had been cross threaded onto the stud damaging the thread profile, but it is not considered that this impaired the function of the rocker assembly. All the rocker valve clearance adjusters showed signs of wear. The engine logbooks showed that the valve clearances were checked and adjusted by the owner approximately every 50 hours. The spark plugs were examined, and they all showed signs of use with some build-up of black and light brown coloured deposits.

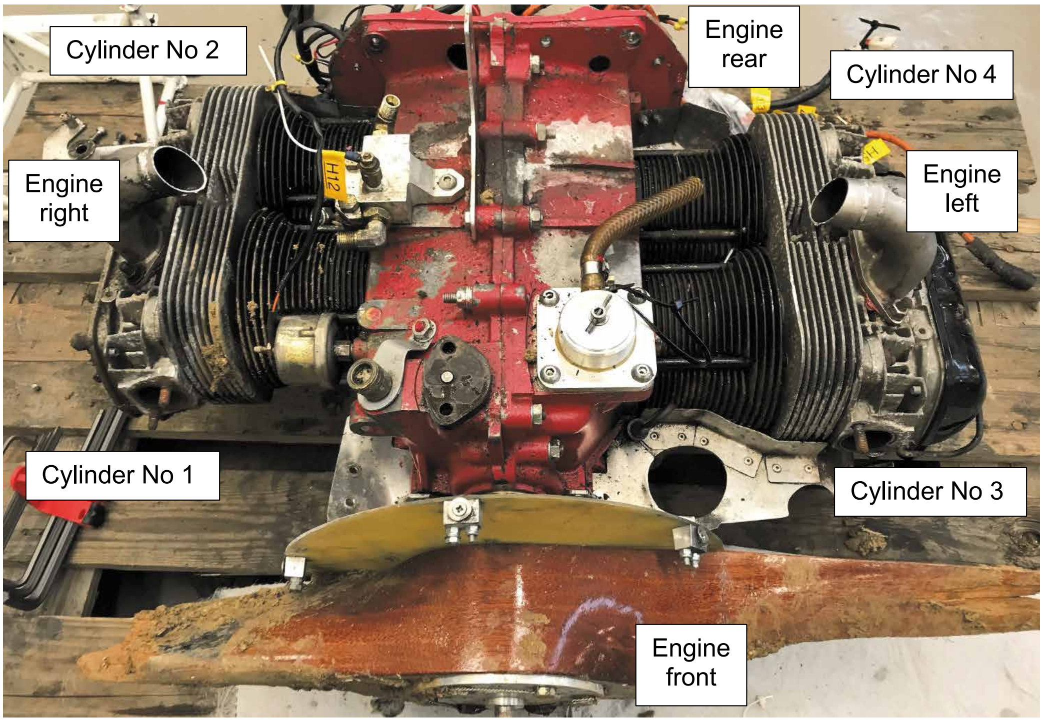


Figure 8

Engine labelling convention

With the rocker assemblies removed, the cylinders were pressure tested to verify cylinder head, piston ring and valve sealing. High pressure air at 50 psi was applied to each cylinder with the piston at bottom dead centre. Air could be heard and felt escaping through the exhaust ports during the test of cylinders 1 and 2. The results are shown in Table 1.

Cylinder	Residual pressure
Cylinder 1	10 psi
Cylinder 2	10 psi
Cylinder 3	37 psi
Cylinder 4	48 psi

Table 1

Cylinder differential pressure test

Both cylinder heads were removed and examined along with the crowns of the pistons (Figures 9 & 10). All the cylinders had evidence of the build-up of combustion deposits. The largest build-up was seen in cylinder 1 with black and white deposits on both the piston crown and the head. Cylinders 2 & 4 showed some build-up of a hard, light brown deposits, whereas cylinder 3 was predominantly a soft black deposit.

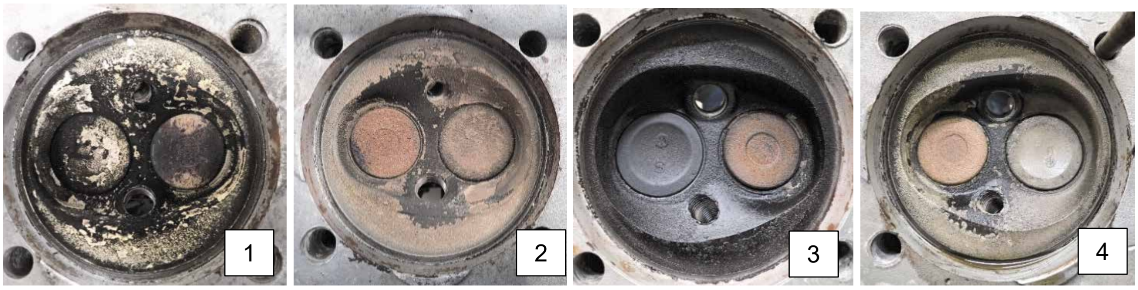


Figure 9
Cyclinder heads

Figure 10
Piston crowns

The valves were removed to facilitate an examination of the valves and their seats. The exhaust valves from cylinders 1, 2 and 3 all showed signs of localised overheating and evidence of uneven seating in the valve seat (Figure 11). All the inlet valves showed signs of carbon build-up on the back face which is thought to be typical for an engine of this age.

Figure 11
Exhaust valve from cylinder 1

The valve seats were examined, and it was noted in cylinder 2 there were crushed light brown deposits on the valve seat sealing face and in the exhaust port. A crack was identified between the inlet port and the larger spark plug hole (Figure 12) with carbon deposit on the exterior surface. All spark plug holes had a helical threaded insert fitted.

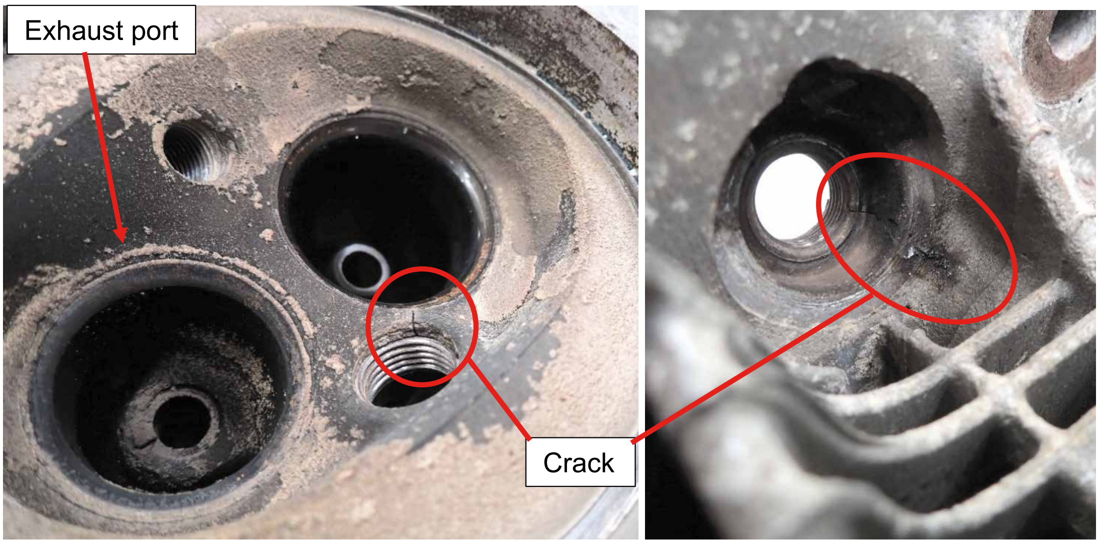


Figure 12

Deposits and crack in cylinder 2

Meteorology

RAF Coningsby is 9 nm south-west of the accident site. At 1150 hrs they reported the surface wind was from 250° at 16 kt, visibility was greater than 10 km, clouds were few at 2,500 ft, temperature was 7°C, dew point 2°C and sea level pressure was 992 hPa. The wind report at 1050 hrs was similar but with gusts to 24 kt. The weather did not change significantly during the time the aircraft was possibly airborne.

Pilot information

The owner of G-BUDW held a valid UK Private Pilot's Licence with a valid Single Engine Piston (Land) rating. He had previously held an Instrument Metrological Conditions (IMC) rating but this was no longer valid.

The pilot's logbook recorded that he had a total of 1,300 flying hours. Since April 2016, when his current logbook started, he had completed 221 hours in G-BUDW. He had completed a pilot medical declaration on the 15 December 2017 which was valid until he reached the age of 70.

Post-mortem

The post-mortem concluded that the pilot died from multiple injuries. There was no evidence that the accident was caused by any medical condition. Toxicology found no evidence of any substance which may have contributed to the accident.

Other information

Partial engine power loss after takeoff

A partial engine power loss is a situation when the engine is producing less than full power but more than idle power. In 2013, the Australian Transport Safety Board (ATSB) published a safety study highlighting the challenges of partial engine power loss after takeoff[4]. The study suggests that pilots are usually trained to deal with a total loss of engine power but often receive little training on partial failures. It highlights that partial failure can be much more difficult to manage because of the choices confronting the pilot and the decisions which need to be made immediately. There can be a strong desire to try to return to the runway to avoid aircraft damage associated with a forced landing on an unprepared surface. However, it can be challenging to judge how far the aircraft will glide and how much height will be lost in the turns. The pilot must also allow for the possibility of further power loss. The study highlights the importance of including partial power loss scenarios in pre-flight planning and pre-takeoff briefings and, if a failure occurs, maintaining aircraft control. CAA Safety Sense Leaflet 1e Good Airmanship[5] explains that attempts to turn back with insufficient energy can result in significant height loss and has resulted in many fatalities.

Carburettor icing

Carburettor (carb) icing is caused by a combination of the sudden temperature drop due to fuel vaporisation and pressure reduction as the mixture passes through the carburettor venturi and past the throttle valve. If the temperature drop brings the air below its dew point, condensation results, and if the drop brings the mixture temperature below freezing, the condensed water will form ice on the surfaces of the carburettor. This ice gradually blocks the venturi, which upsets the fuel/air ratio causing a progressive, smooth loss of power and slowly 'strangles' the engine.

Figure 13 is extracted from the CAA Safety Sense Leaflet 14 about carb icing[6], it shows that for the air temperature and dew point on the day of the accident serious carb icing was likely at any power setting. The grass runway was wet with dew which would have increased the likelihood for carb ice forming during the taxi along the runway. Selecting carburettor heat ON before takeoff, including as part of a power check, may reveal the presence of carburettor ice that might then be removed by more prolonged application. It is not known if the pilot did this prior to takeoff or if the engine temperature would have been high enough for the carb heat system to melt any ice that may have accumulated.

Footnote

4 ATSB – 'Managing partial power loss after takeoff in single-engine aircraft' – available at https://www.atsb.gov.au/media/4115270/ar-2010-055_no3.pdf (accessed 11 May 2020).
5 http://publicapps.caa.co.uk/docs/33/20130121SSL01.pdf (accessed on 1 Jul 2020).
6 http://publicapps.caa.co.uk/docs/33/20130121SSL14.pdf CAA Safety Sense Leaflet 14 - PISTON ENGINE ICING (accessed 9 July 2020).

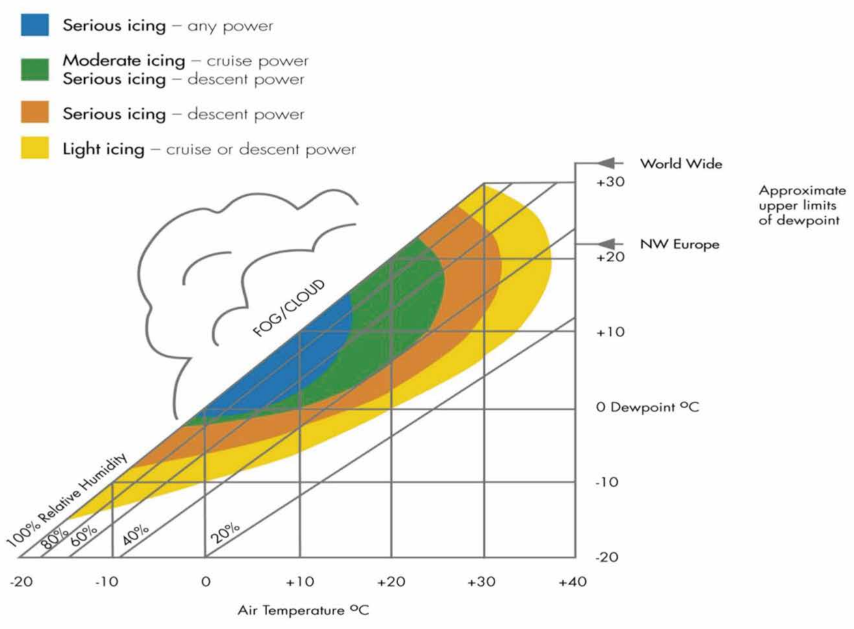


Figure 13

Carburettor icing conditions

Permit to fly aircraft - design changes

In the months preceding the accident it was reported that the engine had been suffering from 'rough running' and a lack of power. To remedy this issue, the owner had fitted the additional electric fuel pump as he believed there to be a fuel starvation issue. It was reported that the electrical pump was originally fitted in series with the engine driven pump, but that the day before the accident flight the fuel system was changed to a parallel configuration. There was no evidence that the pilot had contacted LAA Engineering or an LAA inspector to approve these design changes.

Any modification to an LAA aircraft's design requires approval of the LAA Engineering department. The drawings for the Colibri MB2 do not detail the fuel system so the details of each installation, and each subsequent change, are individually checked by LAA Engineering. So, it would be expected that any pilot/owner would consult with the LAA prior to making any significant design changes, such as fuel system modifications, to their aircraft. The LAA produce a guidance document titled '*When modification approval is not required*'[7] which specifies when approval is not necessary. The guidance concludes by stating '*if there is any doubt over whether LAA Engineering approval is required then clarification should be sought from LAA Engineering'.*

Footnote

[7] LAA TL 3.10 'When modification approval is not required' available at http://www.lightaircraftassociation.co.uk/ engineering/TechnicalLeaflets/Mods%20and%20Repairs/TL%203.10%20When%20Modification%20Approval%20Is%20Not%20Required.pdf (accessed 11 May 2020).

Permit to Fly aircraft – maintenance

CAA Permits to Fly include a condition that all work carried out on the aircraft must be certified by a person authorised by the CAA. For LAA aircraft this person is normally an LAA inspector. There is an exception to this requirement which allows pilots to conduct some maintenance without the need to be certified. The LAA published a guidance document title '*Pilot Maintenance*'[8] which specifies what maintenance a pilot can undertake without the need for further inspection. However, the work undertaken on G-BUDW was beyond that specified in this document so should have been inspected and certified by an LAA inspector prior to flight.

Permit to fly aircraft - maintenance plan

The Air Navigation Order requires that Permit to Fly aircraft are maintained in an airworthy condition. This is achieved by carrying out regular checks on the aircraft's physical condition and undertaking whatever servicing tasks are needed to preserve its condition. Simple servicing tasks are required at regular intervals, typically 50 hours, and more in-depth checks required less frequently. The programme of work needed to maintain an aircraft is called a maintenance schedule. For aircraft with a Certificate of Airworthiness the maintenance schedule is usually specified by the manufacture but for many Permit to Fly aircraft it is left to the owner to develop a suitable schedule. The LAA provide guidance on how to develop a maintenance schedule in their Technical Leaflet TL 2.19 titled 'The LAA Generic Maintenance Schedule'[9] and their website provides a generic schedule for a 50-hour, annual and 3-yearly check[10].

For G-BUDW, the aircraft logbooks recorded that the pilot had changed the engine oil and spark plugs and checked the valve clearances every 50 hours. However, no evidence was found of longer-term maintenance tasks such as engine top-end or complete overhaul.

Permit to Fly aircraft - engine health monitoring

The engine fitted to G-BUDW had accumulated 605 hours since it was last rebuilt. The LAA provide guidance to owners on how to monitor the health of their engine to ensure it continues to be airworthy. LAA Technical Leaflet titled '*Engine overhaul life and operating on-condition*'[11] describes the parameters which should be regularly recorded to detect trends and determine if the engine performance is deteriating. These include, for example, maximum static rpm, rate of climb at best climb speed, oil pressure at a particular cruise rpm, oil consumption and compression in each cylinder.

Footnote

8 LAA TL 2.05 '*Pilot Maintenance*' – available at http://www.lightaircraftassociation.co.uk/engineering/TechnicalLeaflets/Operating%20An%20Aircraft/ TL%202.05%20Pilot%20Maintenance.pdf (accessed 11 May 2020).

9 LAA TL 2.19 '*The LAA Generic Maintenance Schedule*' available at http://www.lightaircraftassociation.co.uk/engineering/TechnicalLeaflets/Operating%20An%20Aircraft/TL%202.19%20The%20LAA%20Generic%20Maintenance%20Schedule.pdf (accessed 11 May 2020).

10 http://www.lightaircraftassociation.co.uk/engineering/Maintenance/Aircraft_Maintenance.html (accessed 11 May 2020).

11 LAA TL 2.23 '*Engine overhaul life and operating on condition*' – available at http://www.lightaircraftassociation.co.uk/engineering/TechnicalLeaflets/Operating%20An%20Aircraft/TL%202%2023%20Engine%20overhaul%20life%20and%20operating%20on-condition.pdf (accessed 5 May 2020).

No evidence was found of regular engine parameter monitoring of G-BUDW's engine. If this type of monitoring had been conducted it is likely that the low compression on cylinders 1 and 2 would have been detected. The LAA Inspector who completed the previous annual inspection reported that he did an engine compression test by rotating the propeller by hand and did not detect any abnormality.

Analysis

Accident flight

The aircraft was seen taking off and turning to the north. Two witnesses reported hearing the engine running rough. The accident site was discovered approximately one hour later. It is not known for certain when the accident occurred or where the aircraft flew after the initial sightings but the fact that the aircraft was not recorded on radar suggests it did not gain significant altitude. There was no record of the pilot contacting any of the air traffic control frequencies in the surrounding area which suggests he did not travel far from the airfield. Additionally, from the witnesses' descriptions of the rough running engine, it is likely that the pilot would have been looking to land as soon as possible. Therefore, the most likely scenario is that after the turn to the north the pilot tried to fly a circuit to the north of the airfield in an attempt to land back on the runway. The impact marks suggest the aircraft was turning to align with the runway when it struck the ground.

Loss of engine power

The investigation identified that the engine was in poor condition with multiple defects which could have caused the loss of engine power and rough running. The most significant of these were the crack in the cylinder head, the split in inlet manifold joint and deposits on the valve seats. The crack in the head of cylinder 2 would have resulted in a reduction in compression and engine power. The split in the manifold would allow air into the manifold, weakening the mixture and causing the engine to run hot.

The deposits on the valves were most likely a mixture of carbon and oil and not untypical for an engine of this age. In cylinders 1 and 2 it was noted that some of the deposit had flaked off the head and there was evidence that these flakes had been caught and crushed in the valve seats. This would have prevented the valves from sealing, resulting in low compression and loss of engine power. From the sealing checks, only cylinder 4 sealed effectively.

The original power output of the engine was not known but with the defects identified during the examination its power would have been severely reduced. The weather conditions on the day were also conducive to carburettor icing and following the long taxi over wet grass, this may have further reduced engine power.

The long-term engine problems are likely to have been caused by the crack in the head of cylinder 2 and the split in the inlet manifold joint. However, it is believed that on the accident flight, a detached carbon flake caught under the exhaust valve of cylinder 1 further reducing the engine's performance to a point where flight could not be sustained.

Approved maintenance planning

Although the checks for the permit to fly had been signed off by the LAA inspector, no evidence of long-term maintenance planning was identified. The engine logbooks recorded the completion of regular annual tasks which were predominantly oil changes and tappet adjustment.

The LAA Technical Leaflet TL 2.23 regarding on-condition monitoring of aero engines, covers the use of automotive engines in light aircraft applications. The manufacturer's recommendations for service and overhaul intervals do not apply to the duty cycle of a light aircraft. The LAA therefore recommends monitoring of various engine parameters and taking appropriate action when deviation from the 'norm' is noted. During the investigation no evidence was found that engine parameters were being regularly recorded.

This investigation demonstrated that a compression check by feel rather than using compression test equipment is not a reliable indication of the condition of the cylinders. The LAA advise in TL 2.23

> *'Other enthusiasts manage without an air supply, simply by turning the engine by hand and feeling the amount of 'bounce' in the propeller, but its much harder to work out where leaks are occurring with this method.'*

Had the checks and servicing been carried out using the LAA guidance in TL 2.19 and TL 2.23 it is likely the crack in Cylinder 2 and the inlet manifold leak would have been identified.

While there was no defined overhaul period for G-BUDW's engine its poor condition indicated that it required a top-end overhaul.

Approval of design changes

The pilot had made several changes to the aircraft fuel system whilst attempting to resolve an engine problem. There was no evidence that these changes had been inspected by a LAA inspector or that they had been discussed with, or approved by, LAA Engineering. Whilst there is no evidence that these contributed to the accident, it is important that owners/pilots should follow the correct inspection and approval process when making changes to the aircraft configuration. The LAA provide guidance on this process and LAA Engineering should be contacted if there is any doubt on whether approval is required.

Partial engine failure

An engine problem in a single engine aircraft need not necessarily result in a fatal accident. If an engine loses power in flight it may be possible to land in a suitable field. However, during this flight it is likely that the pilot experienced a partial engine power loss. This can be particularly difficult to manage. The ATSB report describes the challenge of judging how far the aircraft can fly with partial power.

In this accident it is likely that the pilot felt he had enough height and power to return to the runway. It is possible that whilst trying to fly back to the runway the engine lost further power reducing the glide distance causing the aircraft to impact the ground before reaching the runway. Many fatal accidents have occurred whilst pilots attempt to turn back to the runway following an engine failure on take off. CAA Safety Sense Leaflet 1e *'Good Airmanship'* advises:

> *'In the event of engine failure after take-off, achieve and maintain the appropriate approach speed for your height. If the runway remaining is long enough, re-land; and if not, make a glide landing on the least unsuitable area ahead of you.'*

Conclusion

The aircraft suffered a partial engine failure shortly after taking off. The evidence suggests that the pilot flew a circuit to the north of the airfield attempting to return to the runway but struck the ground just to the north of the runway.

The investigation found the engine was in poor condition with several defects which could explain the loss of engine power. This included a crack in the head of cylinder 2 and a leak in the manifold.

The pilot had made several modifications to the fuel system, but no evidence was found that these had been approved in accordance with LAA requirements. No evidence was found of on-condition engine health monitoring or an established maintenance schedule for the aircraft.

Published: 1 October 2020.

Bulletin correction

After publication it was noted that the captions for figures 9 and 10 were transposed.

The captions in this report have now been corrected.

The online version of this report was corrected on 19 November 2020.

SERIOUS INCIDENT

Aircraft Type and Registration:	Mooney M20K, G-OSUS
No & Type of Engines:	1 Teledyne Continental TSIO-360-LB1 piston engine
Year of Manufacture:	1980 (Serial no: 25-0429)
Date & Time (UTC):	30 May 2020 at 1255 hrs
Location:	Membury Airfield, Berkshire
Type of Flight:	Private
Persons on Board:	Crew -1 Passengers -1
Injuries:	Crew - None Passengers - None
Nature of Damage:	Damage to baggage door, rear fuselage and tailplane
Commander's Licence:	Private Pilot's Licence
Commander's Age:	28 years
Commander's Flying Experience:	165 hrs (of which 50 were on type) Last 90 days - 15 hours Last 28 days - 4 hours
Information Source:	AAIB Field investigation

Synopsis

The aircraft was in level flight and had been flying for approximately 15 minutes when the baggage door opened and detached. It struck the right tailplane and remained wrapped round its leading edge near its tip. This caused the pilot control difficulties and increased drag. The pilot declared a MAYDAY and made a successful emergency landing at Membury Airfield.

The investigation found the safety clip for the internal emergency operating handle of the baggage door was not correctly installed, so instead of holding the handle closed it held it in a slightly open position. During the flight, it seems most likely that this handle moved sufficiently towards the open position to disengage the shoot bolts from the door frame allowing the door to open.

It could not be determined when the safety clip was incorrectly installed or why it had not been noticed.

History of the flight

The pilot had flown the aircraft to Charlton Park Airstrip and whilst there the baggage door had been opened from the outside to allow access to a picnic basket. As it was a hot day, It was left open for the duration of the stay to keep the cabin area cool (Figure 1).

Figure 1

G-OSUS being pushed into a parking position showing open baggage door

Before departure the baggage area was repacked, and the pilot checked the baggage door was securely closed from the outside. Once seated the pilot visually checked the internal handle from his seat and it appeared closed.

The takeoff and climb to cruise altitude was without incident. The weather was good and there was some thermal activity causing light turbulence at times. Approximately 15 minutes into the flight, and just after the aircraft had passed overhead Membury Airfield, Berkshire, there was a loud bang and the aircraft pitched nose-down and rolled to the right. The baggage door had opened and detached. It had struck and remained attached to the right tailplane leading edge near its right tip (Figure 2). The pilot was able to control the aircraft and then declared a MAYDAY whilst he positioned to land at Membury Airfield. During the approach the pilot maintained a higher speed than normal due to the control difficulties and landed on Runway 13, which is 1,000 m long. During the extended ground roll, due to the higher than normal touchdown speed, the pilot steered the aircraft right into a clear space on the airfield and stopped without further incident.

Figure 2

Baggage door on the tailplane right tip, as found after landing, looking forward

Aircraft information

The Mooney M20K is a single engine, four seat light aircraft of primarily metal construction. A baggage door is fitted to allow access to the baggage area behind the rear row of seats. It is hinged at the top and secured at the bottom with two shoot bolts, these extend fore and aft into fittings in the door frame when the operating handle is closed; this handle can also be locked for security. The door also serves as an auxiliary exit and is fitted with an internal emergency handle to allow operation from inside the aircraft. The internal emergency handle will open the door even if the external handle is locked.

The internal emergency handle is fitted with a secondary locking clip to prevent inadvertent operation and there is a cover over the whole mechanism along with a placard providing operating instructions (Figure 3). This secondary locking clip was introduced by the manufacturer in a service bulletin (SB) SB M20-239A, issued in 1988 and mandated by Airworthiness Directive (AD) 88-25-11 which became effective 5 January 1989. This aircraft had this SB/AD embodied.

Figure 3

Internal emergency handle correctly closed and secured by secondary locking clip
(Image shows accident door, placard and cover are missing)

Aircraft examination

The aircraft sustained considerable damage to the right side of the tailplane. The force of the impact twisted the right side of the tailplane rearwards and the left side forwards to such an extent that it was touching the fuselage where normally there is a gap. Several rivets around the tail assembly attachment to the fuselage were 'popped'.

The baggage door was inspected by the AAIB after it had been removed from the tailplane. Photographs taken before the flight and immediately after landing were also studied. These examinations confirmed the positions of the operating handles and other related components.

Closer examination and magnification of Figure 1 shows that the internal handle was in a partly open position before the flight (Figure 4). The image is grainy due to the magnification and the contrast and colour have been adjusted to show the handle more clearly. The image has been rotated 180° to align more with the image in Figure 5, which shows the similar position of the internal operating handle after landing, for comparison.

Figure 4

Extract of Figure 1 showing internal operating handle partially open before flight

Figure 5

Position of internal operating handle after emergency landing

The internal handle features a slot which allows the handle to be opened partly before it starts to move the shoot bolts from the fully extended position. The handle position in the images taken before and after the flight (Figures 4 and 5), show the internal handle approximately in a position where the shoot bolts would not yet have moved and they can be seen extended.

The internal handle had the secondary locking clip installed in the clevis pin, but this was installed under the handle rather than over it, so it did not provide a secondary locking feature. The locking clip is also bent suggesting the handle had been forced down on to the locking clip onto the locking clip (Figure 6). This may have made it appear as though the operating handle was in the correct closed position.

Closer inspection of the clevis pin found that it was loose in its mounting plate rather than the push fit specified. This meant that it was free to drop down which made it impossible to install the locking clip until it had been lifted to the correct position.

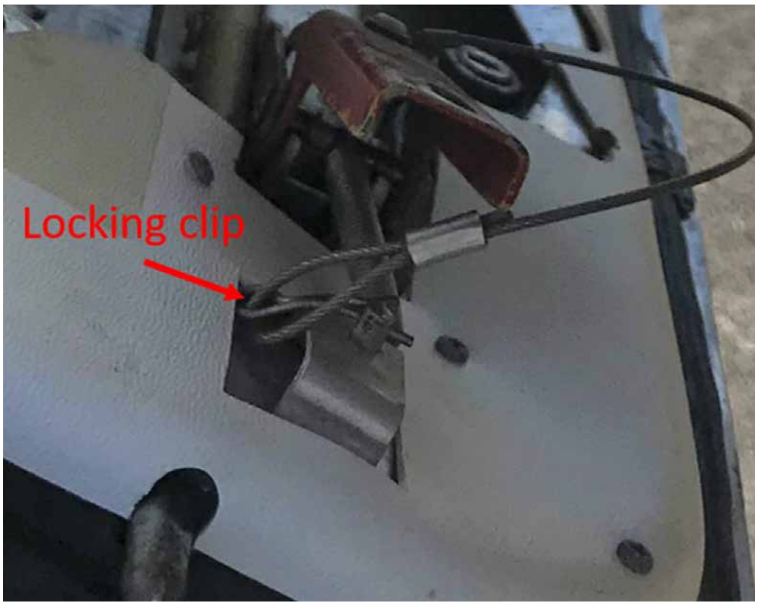


Figure 6

Bent locking clip and partially open internal handle

Personnel

The pilot was correctly licenced to operate this aircraft and since gaining a PPL has voluntarily spent extra time with an instructor practising dealing with various emergency situations, including forced landings. The pilot stated this extra training proved invaluable in this event. The pilot also stated that they had not touched the internal handle since the recent maintenance. This was the fourth flight since then, and the pilot had not had the need to open the baggage door from the inside. He had not seen a plastic cover over the handle at any time.

Maintenance information

In 2019, the aircraft was repainted and in addition to the external paint finish, the internal plastic trim panels were also painted. In order to remove the plastic trim panel from the baggage door, the internal operating handle would have been opened to release the trim panel. On completion of the painting the interior trim panels were certified as being correctly fitted; there was no separate item in the work pack for refitting the baggage door internal emergency operating handle or its cover. The whole work pack for the repaint was certified as complete on 11 September 2019.

The aircraft had undergone other maintenance checks and been flown by several other pilots since the repaint. During the most recent maintenance, an Annual Inspection and Airworthiness Review, completed on 29 May 2020, an 'operational check'[1] of the 'Doors, hatches and windows latching and locking' had been certified as being completed.

Other information

The pilot's operating handbook used by the pilot required in item 10 of the pre-flight check list '*Baggage door – Secure*'. A version supplied by the maintenance organisation for the same item 10 stated '*Baggage door – SECURE and lock before flight*'. Both documents are marked as Revision A. Whether or not the external handle was locked, operation of the internal emergency handle would still open the door.

Analysis

An image taken at Charlton Park before the incident flight, showed that the internal baggage door handle was partially open when the aircraft was parked. It appeared to be in a position where the extension of the shoot bolts would not be affected. Before departure the pilot checked that the baggage door was properly closed, physically from the outside and visually on the inside from his seat but did not see the internal handle was not properly closed. Normal operation of the baggage door is by use of the external handle and this was the only handle that the pilot used.

Inspection of the internal emergency handle showed that it had been incorrectly assembled; the safety clip was fitted under the operating handle rather than above it. The safety clip appeared to be bent, possibly as a result of the operating handle being forced into its closed position over it. This meant the handle was not in the fully closed position and it would have been held slightly open by the safety clip, although the available images suggest it had moved further open than this.

It was not possible to determine exactly when this internal handle and its safety clip was incorrectly installed. They were disassembled, to allow removal and refitting of the trim panel for repainting, in 2019. Since then, the aircraft had undergone maintenance checks and had been flown by several pilots. During the most recent maintenance a check of the

Footnote

1 An 'operational check' is a test used to determine that a system or component or any function thereof is operating normally.

baggage door's correct latching and locking had been certified. Since this maintenance, the aircraft had flown three flights before the incident flight.

Before the flight the pilot had loaded the baggage bay and it is possible that, in the light turbulence experienced during the flight, something shifted and moved the handle to a more open position causing the shoot bolts to disengage. However, this would not explain why the internal handle and safety clip were not properly installed.

Conclusion

The safety clip for the internal operating handle of the baggage door was not correctly installed, so instead of holding the handle closed it held it slightly towards the open position. During flight it seems most likely that this handle moved further open, and sufficiently far to disengage the shoot bolts from the door frame, allowing the door to open. The force of the airflow then detached the door and it struck and became jammed on the tailplane.

It could not be determined when the internal handle and its safety clip were incorrectly installed or why this or the partially open internal handle had not been noticed.

Despite the baggage door jamming on the tailplane, the pilot had sufficient control to allow a safe landing. The pilot maintained a higher speed than normal to ensure the aircraft remained controllable. The pilot attributes the successful outcome to the voluntary additional training undertaken to practise dealing with emergencies.

Published: 15 October 2020.

AAIB Correspondence Reports

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

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

The accuracy of the information provided cannot be assured.

SERIOUS INCIDENT

Aircraft Type and Registration:	Airbus A321-231, G-WUKJ
No & Type of Engines:	2 International Aero engines V2533-A5 turbofan engines
Year of Manufacture:	2019 (Serial no: 8879)
Date & Time (UTC):	16 June 2020 at 1038 hrs
Location:	Doncaster Airport
Type of Flight:	Private
Persons on Board:	Crew - 2 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	None
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	46 years
Commander's Flying Experience:	6,554 hours (of which 3981 were on type) Last 90 days - 57 hours Last 28 days - 51 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

Synopsis

During the takeoff roll, as the aircraft was approaching V_1, the commander identified that the airspeed on the Primary Flight Display was reading zero and rejected the takeoff. Examination of the aircraft found insect larvae within one of the pitot probes. The aircraft had been parked for nearly 12 weeks prior to the flight. The operator has taken safety action to introduce a procedure that flushes the static and total pressure lines on any aircraft that has been parked for more than three days before it is returned to operation.

History of the flight

G-WUKJ had been parked at a remote stand at Doncaster Airport since 25 March 2020. After arrival it was prepared for long term parking in a 'flight-ready' condition, in accordance with the Aircraft Maintenance Manual (AMM). This was accomplished by a local Part 145 Aircraft Maintenance Organisation (AMO). The aircraft was maintained in accordance with the AMM whilst it was parked.

On 9 June 2020, as part of the long-term parking requirements defined in the AMM, the Air Data System was flushed.

On 15 June 2020, a work package was carried out preparing G-WUKJ to return to service. The pitot covers, which had been in position during the time the aircraft was parked, were removed.

All times are UTC

On 16 June 2020, the aircraft was released to service for a non-revenue flight to Stansted. As the aircraft had been on the ground for an extended period, the commander and first officer decided to complete separate walkarounds as a precaution; they found no faults.

Shortly after 1030 hrs, the flight crew prepared the aircraft for flight, taxied to the holding point and were given clearance to takeoff on Runway 20. The commander reported that, during the initial acceleration, his Primary Flight Display (PFD) trend arrow indicated an increasing airspeed. As the aircraft continued to accelerate his attention was drawn to a number of birds that were in the takeoff path. When his instrument scan returned to the PFD he identified that the speed indication was reading zero. He immediately cross checked with the first officer and called to reject the takeoff. Maximum reverse thrust and automatic braking were applied and the aircraft stopped on the runway. The pilot reported that takeoff was rejected at 120 kt, which was also V_1.

Recorded information

Data from the aircraft's flight recorder showed that the aircraft reached an airspeed of approximately 128 kt as recorded by the Integrated Standby Instrument System (ISIS). This occurred one second after the crew had initiated stopping action as the aircraft attained V_1. G-WUKJ slowed below 30 kt airspeed, the lowest value recorded by the ISIS, 1,200 m from the beginning of the 2,751 m runway.

Aircraft examination

The post flight report produced a failure message '*34-12-34 ADR1*' associated with a flight control ECAM warning in the No 1 Air Data Reference (ADR1). Troubleshooting performed by the AMO transposed the No 1 and No 3 Air Data Inertial Reference Units (ADIRUs) and after a successful ground test, released the aircraft for the ferry flight.

During the subsequent takeoff, at approximately 1540 hrs, the aircraft performed a low speed rejected takeoff as the commander's PFD was still not registering an air speed.

Further troubleshooting over the following two days finally found three small insect larvae, approximately the size of a grain of rice, within the No 1 pitot probe. These larvae were liberated whilst performing a pitot probe flush, which was advised by the aircraft manufacturer. The larvae were not retained to enable further identification of the insect species.

The operator concluded that the insect larvae may have been deposited in the pitot probe whilst it was parked with the pitot probe covers fitted. To prevent differential pressure measurement issues in the air data system[1], pitot probe covers supplied by the aircraft manufacturer do not completely seal the probes, it is therefore possible that an insect could enter the air data system during prolonged parking. It cannot be ruled out, however, that the larvae were deposited once the aircraft had been prepared to return to service on 15 June or an insect had been within the pitot probe covers before they were fitted.

Footnote

[1] If sealed pitot probe covers are used, they can increase the pressure in the air data system when they are fitted. This could be identified by the system as a real airspeed and could, due to the aircraft's safety logic, cause an inadvertent deployment of the Ram Air Turbine whilst the aircraft is electrically powered up on the ground.

Safety actions

The operator has introduced a requirement to flush all total and static pressure lines before any aircraft is returned to operation after it has been parked for more than three days.

The operator is also looking to identify better pitot probe covers that may offer better protection than those currently used.

The aircraft manufacturer is looking to update the aircraft AMM Return to Operations task to require air data system flushing prior to the next flight after prolonged time on the ground.

Bulletin correction

Prior to publication, it was noted that the aircraft registration was incorrectly stated as G-WUJK instead of G-WUKJ in the history of the flight and in the recorded information sections of the report.

This was corrected online prior to publication on 12 November 2020.

SERIOUS INCIDENT

Aircraft Type and Registration:	Cessna 510 Citation Mustang, OE-FNP
No & Type of Engines:	2 PW615F/A turbofan engines
Year of Manufacture:	2009 (Serial no: 0185)
Date & Time (UTC):	5 August 2020 at 0605 hrs
Location:	Jersey Airport
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 2 Passengers - 4
Injuries:	Crew - None Passengers - None
Nature of Damage:	None
Commander's Licence:	Commercial Pilot's Licence (Aeroplanes)
Commander's Age:	44 years
Commander's Flying Experience:	5,348 hours (of which 3,732 were on type) Last 90 days - 153 hours Last 28 days - 50 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

Synopsis

During the approach, ATC told the crew they were number one in sequence and instructed them to contact the Tower frequency. The crew continued the approach and landed without contacting the tower or receiving landing clearance.

History of the flight

The crew of OE-FNP was being radar vectored for an approach to land on Runway 26 at Jersey Airport. They were receiving an ATC service from Jersey Approach. As the aircraft captured the glideslope on the ILS, the crew were told they were number one and instructed to contact Jersey Tower frequency. The crew completed the landing checklist, turned the landing lights on and preceded to land without contacting the tower or receiving a landing clearance. After vacating the runway, they were informed that they were still on the approach frequency.

The crew felt that they must have misinterpreted the ATC instructions regarding their position in the sequence as a landing clearance. There was no other traffic in the vicinity at the time and the tower controller was aware of their presence and expecting them. The commander commented that the crew were not fatigued, distracted or overloaded yet misinterpreted the instructions they received. He emphasised the importance of checking if there is any doubt as to the clearance received.

ACCIDENT

Aircraft Type and Registration:	Hawker Hurricane 1, G-HRLI
No & Type of Engines:	1 Rolls-Royce Merlin III piston engine
Year of Manufacture:	1940 (Serial no: 41H-136172)
Date & Time (UTC):	1 June 2020 at 1203 hrs
Location:	Duxford Airfield, Cambridge
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Landing gear and lower fuselage damaged
Commander's Licence:	Private Pilot's Licence
Commander's Age:	60 years
Commander's Flying Experience:	850 hours (of which 8.3 were on type) Last 90 days - 1.4 hours Last 28 days - 0.2 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot and further enquiries by the AAIB

Synopsis

While landing with a crosswind the aircraft made an uncommanded right turn that was not corrected, and the landing gear collapsed. The landing technique, the pilot's lack of recency and the hard, dry runway surface may have been contributory factors. The operator will require that less experienced pilots do not operate the aircraft with a crosswind component above 5 kt from the right.

History of the flight

The aircraft was returning to land on the grass Runway 06 at Duxford after a 20 minute engine maintenance flight. The pilot observed a crosswind from right of the landing direction and approached at a slight angle to the runway in order to land more into wind. The aircraft touched down on all three wheels as the pilot intended but bounced slightly and began to turn to the right.

The pilot reported that as the aircraft decelerated and rudder effectiveness decreased, he found it necessary to use brake to control direction and was unable to prevent the aircraft from turning further right. There was then a pronounced bounce, during which the aircraft pitched forward into an approximately level attitude and the tailwheel was no longer in contact with the ground. At what he estimated to be around 20 mph, first the left and then the right landing gear collapsed. The aircraft remained upright and there was no fire, but the aerodrome rescue and firefighting service applied a fire-supressing agent as a precaution.

The pilot had been wearing a full harness and helmet and, after switching off the ignition and electrical system, vacated the aircraft uninjured.

Figure 1

G-HRLI after the accident and application of fire-suppressing agent

Aircraft information

General

The Hawker Hurricane is a historic single-engine fighter aircraft of 1930s design with a tailwheel configuration. The main landing gear is located ahead of the aircraft centre of gravity and retracts towards the fuselage centreline. The tailwheel does not retract and castors freely.

Mass and centre of gravity

The aircraft was reported to be below its maximum landing weight, with its centre of gravity (cg) located approximately 55.4 inches aft of datum. The forward and aft cg limits specified in the aircraft's permit to fly were 54.0 and 58.0 inches aft of datum.

Restoration and maintenance

G-HRLI was the subject of a major restoration completed in 2018, since when it had flown 34 hours. The pilot reported no history of relevant defects or occurrences since the restoration, and the maintenance organisation responsible for the aircraft confirmed that its permit-to-fly was valid.

Aircraft and site examination

An examination of the aircraft after removal from the accident site did not reveal any evidence of pre-existing mechanical defects that might have contributed to the loss of control or landing gear collapse.

Ground marks observed after the accident indicated that the aircraft began to slide in approximately the landing direction shortly before the landing gear collapsed.

Meteorology

The pilot reported that the forecast wind was from 080° at 10-12 kt and that on touchdown it was from approximately 100° at 10-15 kt. The wind speed observed in the control tower at around the time of the accident was from 110° at 7 kt. Visibility was more than 10 km, the temperature was 23°C and the QNH was 1007 hPa.

Airfield information

Duxford has two runways, one tarmac and one grass, aligned 06/24. The grass Runway 06 is 880 m long, with a clear straight-in approach, and was dry and hard at the time of the accident. There was no indication that the runway surface was proving hazardous to other aircraft, but the surface was bumpy in places (mainly towards the Runway 24 touchdown end).

Personnel

The pilot had accumulated just over 8 hours flying experience in the Hurricane, all of which were flown solo because at the time there were no examples that accommodated more than one person. Before doing so he conducted a course of training in relevant aircraft, including North American T6 'Harvard' dual control trainers of the type used for this purpose when the Hurricane was in military service.

The pilot also flew a Pitts Special tailwheel aerobatic aircraft, which has different but also potentially challenging landing characteristics. The wing on that aircraft has a symmetrical section whose angle of attack is considerably below the stalling angle of attack when the aircraft lands in a three-point attitude, and it is not usual to apply full tail-down elevator as early in the landing run as might be desirable in a Hurricane. The Pitts Special's brakes and rudder are both effective, and some pilots favour brake as a directional control on landing in circumstances where rudder would be more appropriate in a Hurricane.

The pilot reported that he had not flown the Hurricane for several weeks because private flying had stopped nationally for public health reasons except for specific purposes including maintenance. Recently he had flown a weight-shift microlight in which pitch, yaw and roll control inputs are reversed compared to fixed wing 'three-axis' aircraft such as the Hurricane. He had also flown approximately 15 minutes in the Pitts Special immediately before flying the Hurricane on the day of the accident. He considered that his lack of relevant currency may have reduced his ability to anticipate and make appropriate control inputs on landing.

Operational control

Civil Aviation Publication (CAP) 632 – *'Operation of Permit-to-Fly ex-military aircraft on the UK register'* describes the requirements for this type of operation. Among other things it recommends training and currency criteria for pilots of high-performance propeller-driven aircraft.[1]

In accordance with CAP 632, the operator of G-HRLI specified in its Operational Control Manual (OCM) that pilots with more than 450 hours as pilot in command were considered 'experienced'. In order to self-authorise a flight, they required a minimum experience after training on the Hurricane of five hours on that type or similar types. The operator reported that the pilot had sufficient experience on the aircraft to self-authorise but that the flight was also authorised by its chief pilot. It considered the Harvard to be a similar type for the purposes of its OCM.

Other information

Crosswind handling

When the Hurricane was designed most aerodromes were grass fields on which landings were not constrained to runways and crosswinds could usually be avoided.

On the ground, in the absence of an opposing force, an aircraft's vertical tail surfaces usually tend to turn it into wind or to 'weathercock'.[2] This tendency is pronounced on tailwheel aircraft like the Hurricane whose main wheels are ahead of the aircraft cg, and may become uncontrollable if the cg moves beyond the edge of effective mainwheel contact (Figure 2).[3]

Applying into-wind aileron helps prevent the upwind wing from lifting and may provide some beneficial yaw opposing the turn. Maintaining tailwheel contact can provide a stabilising reaction behind the aircraft cg but, because the tailwheel of the Hurricane castors freely, it does not provide directional control and any resistance is reduced if the surface is hard. Braking tends to pitch the aircraft nose down (tail up), removing any beneficial resistance arising from tailwheel contact.

Diagram (a) shows the wind aligned with the landing direction. Diagram (b) shows a crosswind from the right. The aircraft has turned towards the wind and the path of momentum from the aircraft cg is at the outside edge of effective mainwheel contact. The castoring tailwheel is aligned with its path over the ground and provides little stabilising reaction. Without corrective control inputs the rate of turn to the right will increase. The further aft the cg, the more pronounced this effect will be.[4]

Footnote

[1] https://publicapps.caa.co.uk/docs/33/CAP632_02MAY2018_Edition7.pdf [accessed September 2020].
[2] In some cases, for example if the main landing gear is sufficiently far behind the aircraft centre of gravity, this effect may be reversed.
[3] Based on Thurston, D.B. (1995) Design for Flying, 2nd edition, McGraw-Hill.
[4] The aft position of the cg is exaggerated in diagram (b) to illustrate this.

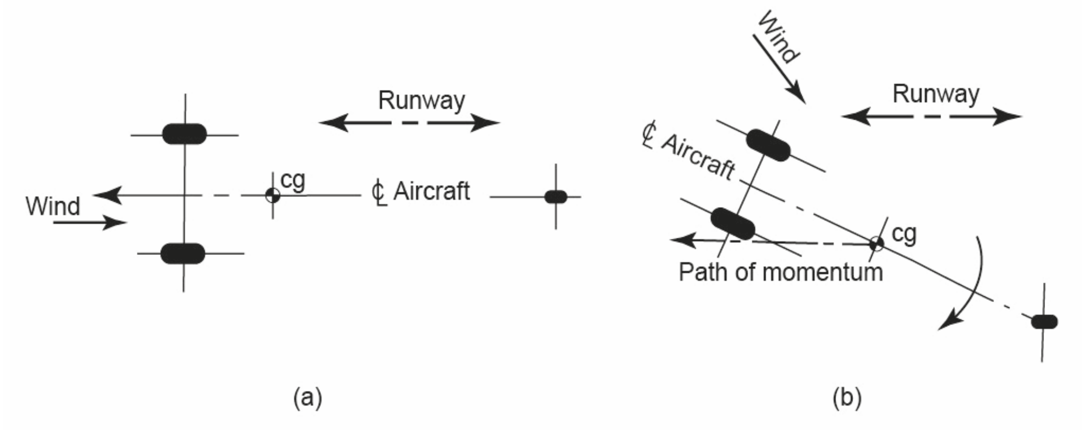


Figure 2

Plan view of landing gear and centre of gravity.
Mainwheels at left of each diagram

Aircraft of similar configuration do not necessarily have similar ground handling characteristics. For example, the contemporary Spitfire and Hurricane both have a tailwheel configuration, but on the Hurricane the cg is considerably further behind the mainwheels than on the Spitfire. Consequently, in the absence of opposing control inputs, a swing on landing will develop more readily in the Hurricane than in the Spitfire.[5]

A tail-down attitude on the ground results in some blanking of airflow over the rudder and fixed fin. Reduced airflow over the fin reduces the weathercock tendency but also reduces rudder effectiveness. If the loss of rudder effectiveness is greater than the reduction of weathercock tendency, the overall effect is to make the aircraft less controllable in yaw when the tail is down.

As airspeed decreases the aerodynamic controls become less effective, and the application of full opposite rudder may be insufficient to maintain directional control if any unintended turn is not corrected promptly, resulting in an increasingly rapid and uncontrollable swing, known as a ground loop. This does not necessarily cause damage if the aircraft comes to rest before hitting an obstacle.

The total wind speed and direction are important factors in a crosswind, as well as the crosswind component itself. A 20 mph wind 30° from the landing direction will produce a 10 mph crosswind but also a 17 mph headwind, whereas a 10 mph wind at 90° to the landing direction will produce the same crosswind but no headwind. The former provides greater control effectiveness throughout the landing roll.

When its engine is running the Hurricane's propeller rotates clockwise when viewed from behind. In the three-point attitude a down-going blade (on the right of the propeller disc)

Footnote

5 The distance between main and tail wheels is approximately the same for both types, but on the Hurricane the distance from the mainwheels to the cg is approximately double that for the Spitfire.

has a greater angle of attack than an up-going blade on the left, moving the effective centre of propeller thrust to the right and producing a tendency to yaw left. Also, the propeller produces significant gyroscopic effects even at low power, and any tendency for the aircraft to pitch nose down will induce a yaw to the left. Correspondingly, yaw to the right will cause a nose-down pitching moment. Spiralling propeller airflow acting on the vertical surfaces of the aircraft also induces yaw to the left, and is most pronounced at high power and low airspeed.

Whereas these effects of propeller motion are likely to produce a left yawing tendency on the ground, they are most prominent with some power applied and the pilot and operator of G-HRLI stated that in their experience the aircraft was more challenging to land in a crosswind from the right.

The brakes on G-HRLI were of the type originally fitted to the Hurricane. Though adequate for taxiing and powerful enough to produce a nosedown pitch if applied firmly, they are prone to fading in prolonged use and the rudder is considered the most effective means of directional control on landing.[6]

Flight manuals

The permit to fly specified that the aircraft *'shall be operated in accordance with the relevant Pilot's Notes, Aircrew Manual or the manufacturer's prescribed operating limitations and requirements.'*

Air Publication (AP) 1564A – *'Pilot's Notes',* was the original Royal Air Force document for the Hurricane I. The pilot provided the AAIB with a copy of AP 1564B&D, the pilot's notes related to the later Mark II and IV versions of the Hurricane fitted with uprated engines.

Appendix 1 of the operator's OCM described the operating limitations and handling techniques for G-HRLI, based on AP 1564A and with additional material. It specified a crosswind limit of 10 kt for 'inexperienced' pilots and 15 kt for 'intermediate and experienced pilots', with a maximum surface wind of 20 kt.

There are several differences between AP 1564A and AP 1564B&D, partly reflecting the differences between the aircraft themselves, including in operating data and the level of detail provided regarding handling techniques. For example, the two documents recommend different landing speeds. The effect of these differences is that the approach speeds recommended for a Hurricane II are approximately 10% higher than for a Hurricane I.

The April 1940 revision of AP 1564A provides the following guidance on *'landing across wind'*:

> *'The aeroplane can be landed across wind but it is undesirable that such landings should be made if the wind exceeds about 20 m.p.h.'*

Footnote

6 Source: AAIB discussions with other Hurricane operators.

The edition of AP 1564B&D shown to the AAIB did not contain guidance on crosswind landings. Pilot's notes for the Hurricane produced by the Air Transport Auxiliary in 1944 state:

> *'The aircraft presents no unusual difficulties in taking off or landing in moderate crosswinds, providing the correct cross wind technique is used... No attempt to take-off or land should be made if the cross wind exceeds 20 mph at 30° to the runway.'*

The operator's OCM contained the following guidance:

> *'The Hurricane is ground loop prone, but with a right-hand cross wind it is particularly so. When the wind is from this direction during the landing roll the aircraft has the possibility to swing into wind. In right hand wind conditions pilots are to be aware of the ground loop possibility and reconsider the landing runway. The Pilot should be ready to counter the slightest swing which uncorrected will quickly escalate into a loss of directional control. The brakes will not be effective in stopping a ground loop once it is underway but provided there are no obstructions in its path the aircraft should come to rest in a safe position.'*

Landing techniques

Tailwheel configured aircraft can be landed in a three-point attitude, in which touchdown occurs on the main and tail wheels simultaneously; or on the mainwheels first, known as a 'wheeler', in which the aircraft is landed in a level attitude. Landings can also be achieved in any attitude between these and, less conventionally, by touching down on the tailwheel first.

A three-point landing is achieved when the landing attitude is closer to the stalling angle of attack than for a wheeler. A wheeler, being at a shallower angle of attack, must be flown at a higher airspeed and therefore requires a longer landing run, but has the advantage that the aerodynamic controls are more effective at the outset. A 'tail-low wheeler' involves both higher landing speed and less effective controls but is the preferred technique for some aircraft. Landing on the tailwheel first tends to pitch the aircraft nose down and the mainwheels may then touch down with sufficient energy to cause the aircraft to bounce.

Flight manuals sometimes offer guidance on the appropriate technique, but the versions of AP1564 seen by the AAIB did not specify a landing attitude. Other guidance applicable to the Hurricane[7] likewise does not specify the landing attitude but indicates that once the tailwheel is on the ground the control column should be held fully rearwards to offer the best directional control and to counter any nose-down pitching tendency.

Video footage showed that immediately before landing the aircraft was in a 'tail-low wheeler' attitude but rotated quickly into a three-point or slightly tailwheel-first attitude on touchdown. The mainwheels became airborne again briefly and on the next touchdown the aircraft began to turn to the right. The tail lifted several times, followed by a more pronounced

Footnote

[7] Hurricane Aircrew Manual, Royal Air Force Battle of Britain Memorial Flight.

nosedown pitch, and a trail of dust from the mainwheels indicated they were in contact with the ground and probably sliding sideways. The tailwheel then remained off the ground until the landing gear collapsed.

The video is not clear but appears to show the elevator approximately neutral throughout. The ailerons are not in view until quite late in the sequence, when it appears into-wind aileron was applied. The rudder does not appear to be significantly deflected at any time.

Survival aspects

The aircraft's canopy slides rearwards and can be opened in flight. If the aircraft becomes inverted on the ground the escape hatch on the right of the cockpit can only be opened if the canopy is locked fully rearwards. The operator's OCM stated:

> *'To facilitate exit during an emergency it is recommended that the cockpit canopy is locked open during take-offs and landings. Pilots may weigh up the conflicting risks if they consider an open canopy will create a distraction or further hazard and elect to take-off and/or land with the canopy closed.'*

Video footage indicated that the canopy was open during the landing but did not show if it was locked fully rearwards.

Analysis

The aircraft centre of gravity was within limits. The open canopy, if locked fully rearward, would have assisted escape had the aircraft become inverted, and was a significant survival precaution.

The pilot was current for the flight as defined in the operator's OCM and had been authorised to conduct it.

The wind recorded at the aerodrome suggests a crosswind within the limits described in relevant pilot's notes. However, the surface wind reported by the pilot would have involved a crosswind component of up to 11 mph; sufficient to make ground handling more challenging.

Landing speeds recommended in the pilot's notes shown to the AAIB, relevant to the later Hurricane II, are higher than those for a Hurricane I. The tail-low wheeler attitude shown in video footage shortly before touchdown, and the bounce shortly afterwards, indicates that the aircraft was slightly fast for a three-point landing. Accordingly, the aircraft was probably quite light on its wheels during at least the early part of its ground roll, increasing any tendency to bounce and slide. Subsequent braking and the propeller's gyroscopic reaction to right yaw would have tended to raise the tail, and there was no obvious tail-down elevator applied to oppose it. The approximately neutral elevator position is consistent with a technique appropriate to the Pitts Special that the pilot also flew. There was no evidence that the pilot had transferred control input habits from weight-shift aircraft he had flown previously.

The apparent absence of opposing rudder input indicates that additional directional control was available.

When the aircraft bounced while turning to the right the tail lifted and it is likely most of the aircraft's weight was supported on the left mainwheel. The aircraft's momentum being largely in the landing direction, and its cg behind the mainwheels, the swing to the right became more pronounced and the aircraft began to slide in the landing direction. This exceeded the side loads for which the landing gear was designed, and it collapsed.

In the absence of any reported defects, such as a binding right brake, it is likely that the loss of control was a result of insufficient or inappropriate control inputs.

Conclusion

The crosswind on landing induced a turn to the right. The reported application of brake and an absence of tail-down elevator coincided with the aircraft bouncing and pitching forward on the hard, undulating runway surface, aggravating the effects of the swing. In the absence of effective control inputs to oppose the swing, the aircraft began to slide sideways, eventually causing the landing gear to collapse. The pilot considered that his lack of relevant currency may have reduced his ability to anticipate and make appropriate control inputs on landing.

Safety actions

> The pilot intends to conduct refresher training in a relevant dual control aircraft such as the Harvard before flying the Hurricane after a significant absence. The operator will amend its Operational Control Manual to require that pilots new to the type with less than 5 hours experience on equivalent types will be limited to a maximum 5 kt crosswind component from the right.

SERIOUS INCIDENT

Aircraft Type and Registration:	Boeing 787-900, VH-ZND
No & Type of Engines:	2 General Electric 1B P2G01/02 turbofan engines
Year of Manufacture:	2018 (Serial no: 63390)
Date & Time (UTC):	9 February 2020 at 1300 hrs
Location:	London Heathrow Airport
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 13 Passengers - 224
Injuries:	Crew - None Passengers - None
Nature of Damage:	Tail strike sensor damaged
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	52 years
Commander's Flying Experience:	13,538 hours (of which 562 were on type) Last 90 days - 60 hours Last 28 days - 17 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot and further enquiries by the AAIB

Synopsis

The aircraft was departing from Runway 27R at London Heathrow Airport (EGLL) in strong and gusty wind conditions. The surface wind passed by the Tower controller with the takeoff clearance was 220° at 28 kt gusting 44 kt. Shortly after aircraft rotation was initiated, variations in airspeed were experienced combined with larger than normal pitch control inputs on the Pilot Flying's (PF) control wheel, which resulted in the tail strike sensor contacting the runway surface.

History of the flight

The aircraft was on a scheduled flight from London Heathrow Airport to Perth Airport in Australia. Following a normal engine start and taxi, the aircraft was cleared for takeoff from Runway 27R with the surface wind reported as 220° at 28 kt gusting 44 kt. Acceleration was normal in the strong wind and, at V_R of 172 KIAS, the PF initiated a rotation which was coincident with a strong gust. Shortly after becoming airborne, the EICAS TAIL STRIKE message was displayed. The crew elected to hold to the southwest of Heathrow at 6,000 ft whilst they carried out relevant actions from the Quick Reference Handbook (QRH), which prevented aircraft pressurisation, so prepared to return to Heathrow. The aircraft was then radar-vectored for an approach to Runway 27L at Heathrow, where an overweight landing was made.

Aircraft information

Tail strike protection system

The Boeing 787 is fitted with a tail strike protection system that automatically adjusts the position of the elevators so as to reduce the potential for tail contact with the ground during takeoff and landing. The system does not degrade takeoff performance.

Tail strike detection and alerting system

Tail strike detection is provided by a 2" blade sensor fitted to the rear lower fuselage of the aircraft (Figure 1). If the electrical circuit within the sensor is compromised due to contact with the ground, a TAIL STRIKE caution message is displayed on EICAS after five seconds. This is accompanied by an aural warning and master caution light being presented in the cockpit.

Figure 1
Tail strike sensor

Aircraft examination

After landing, it was identified that the tip of the tail strike detection sensor (Figure 2) had been abraded due to contact with the runway. No further damage was found.

Figure 2
Damage to aircraft tail strike sensor

Recorded information

Flight data was available from the aircraft's Continuous Parameter Logging (CPL)[1] system and FDR. Parameters included the aircraft's airspeed, the position of its wing spoilers, cockpit control columns and wheels, and pitch rate and tail height (which indicated the distance between the tail strike detection sensor and the ground). The aircraft manufacturer advised that due to factors including aircraft loading and runway slope, the tail height parameter may not always reach zero when the aircraft tail contacts the ground.

The aircraft was correctly configured for takeoff, with the flaps set to FIVE, and V_R was 172 kt.

The data showed that during the takeoff run, there were airspeed fluctuations consistent with the gusty wind conditions. Upon reaching an airspeed of 160 KIAS, the airspeed rapidly increased to 175 KIAS, at which point the PF initiated the rotate (Figure 3 - Point A).

Footnote

1 The function of the CPL is similar to a Quick Access Recorder (QAR) in that it provides operators with data that may be wirelessly transmitted from the aircraft for use by a flight data monitoring program.

As the aircraft pitched up, the airspeed reduced to 172 KIAS, where it briefly stagnated (Figure 3 - Point B). The PF had progressively moved the control column aft to 4° (Figure 3 - Point C) at which point the pitch rate was just over 2°/s; the maximum aft movement of the control column was 9.8°. The control column was then moved slightly forward (Figure 4 - Point D) to 3°, but the pitch rate increased to 3.2°/s. The airspeed then started to increase, which coincided with the PF pulling back on the control column whilst also moving the control wheel from 20° counter-clockwise (CC) to 33° CC (Figure 3 - Point E). This caused the left spoilers to further deploy from 5° to 20°.

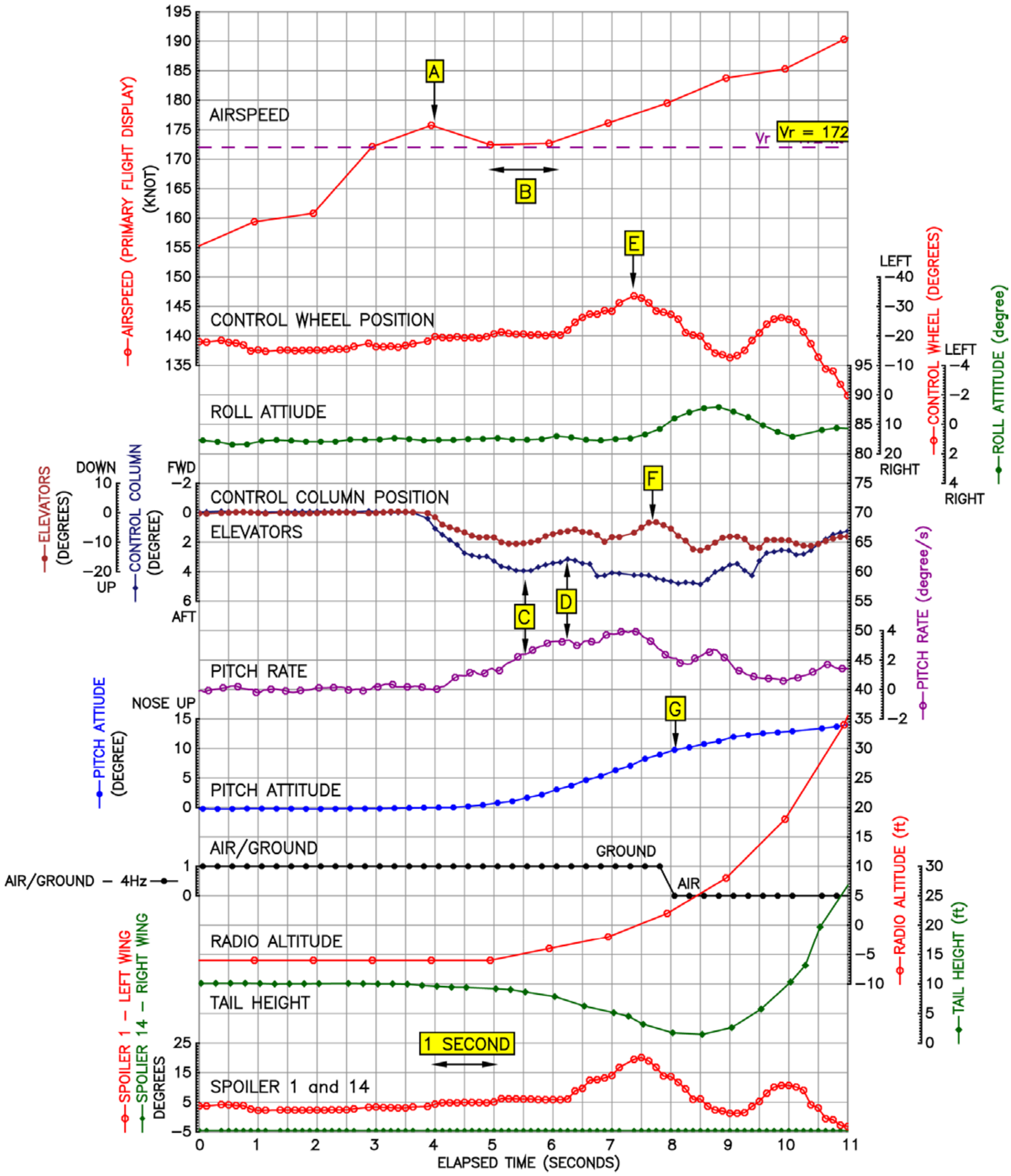


Figure 3

Salient flight data parameters

As the pitch attitude increased through 6.3° nose-up, the pitch rate was nearly 4°/s, and the calculated tail height above the runway was 4.5 ft. The aircraft's tail strike prevention system then started to move the elevators (Figure 3 - Point F), which reduced the pitch rate to just over 2°/s. The pitch attitude at takeoff was about 9.7° (Figure 3 - Point G) and the tail height indicated just less than 2 ft.

The aircraft manufacturer analysed the FDR and CPL data and stated:

> *'The near tail contact was the result of a combination of factors including: high pitch rate close to lift-off, airspeed stagnation, and control wheel usage deploying spoilers on the left wing. The high pitch rate allowed pitch attitude to increase towards the tail contact attitude prior to airspeed reaching lift-off speed. The deployed spoilers on the left wing decreased lift and necessitated a higher pitch attitude for lift-off.'*

Weight and balance

The aircraft weight at takeoff was 253,400 kg, which was below the Maximum Take Off Weight (MTOW) permitted of 254,011 kg, with a CG position of 22.1% Mean Aerodynamic Chord (MAC). The forward limit at that weight, as shown on the load sheet, was 20.25% MAC with the aft limit 24.3%.

Meteorology

General situation

On 9 February 2020, Storm Ciara, which was the most severe storm of the 2019/2020 season, brought strong winds and heavy rainfall across the UK. At the time of the incident, an active occluded front was crossing the London Terminal Manoeuvring Area (LTMA), which included Heathrow, with intense rainfall and strong south-westerly winds.

London Heathrow Airport

METAR observations for Heathrow were obtained for the hours preceding the time of the incident. The observations showed generally south-westerly winds with mean speeds of 26 to 29 kt and gusts of 37 to 45 kt. The main cloud base was 1,400 to 1,500 ft, with outbreaks of rain reducing the visibility to 6 km at times. However, visibility lowered just after midday to 3,900 m with cumulonimbus cloud being detected in automatic observations.

The observation for 1250 hrs, closest to the time of the incident, indicated a mean wind speed of 27 kt from the southwest with gusts to 44 kt. The synoptic weather, which contains additional information, was obtained for 1300 hrs and 1400 hrs. It showed that the highest gusts in the preceding hour were 47 kt, easing slightly to 45 kt in the following hour. The surface chart is shown below at Figure 4.

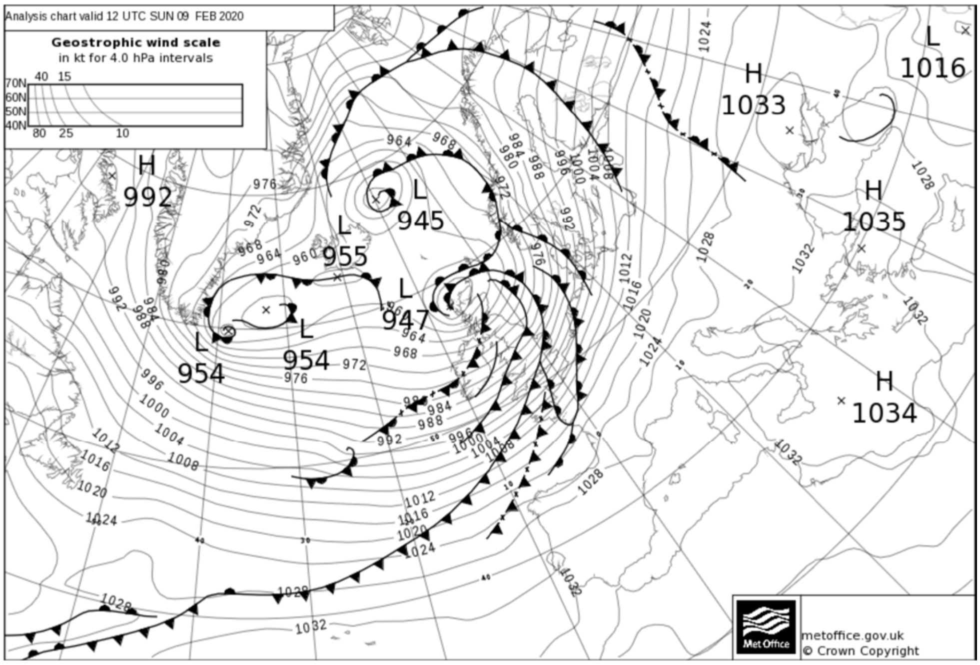


Figure 4

Surface analysis chart valid at 1200 hrs UTC on 9 February 2020

London Heathrow Airport METARs

091250Z EGLL EGLL 091250Z AUTO 22027G44KT 6000 -RA SCT015/// BKN 020/// OVC044////////CB 12/11 Q0989 RERA TEMPO SHRA

091320Z EGLL EGLL 091320Z AUTO 22027G40KT 9999 -RA SCT015/// BKN022/// OVC044/////////CB 12/11 Q0988 NOSIG

Other information

Tail contact pitch angle

The pitch attitude for tail contact is 9.7° with wheels on the runway and landing gear struts extended. A normal lift off pitch angle is between 6° and 7.5° giving a minimum tail clearance height of 29 inches (74 cm). The normal tail clearance profile is shown at Figure 5 below.

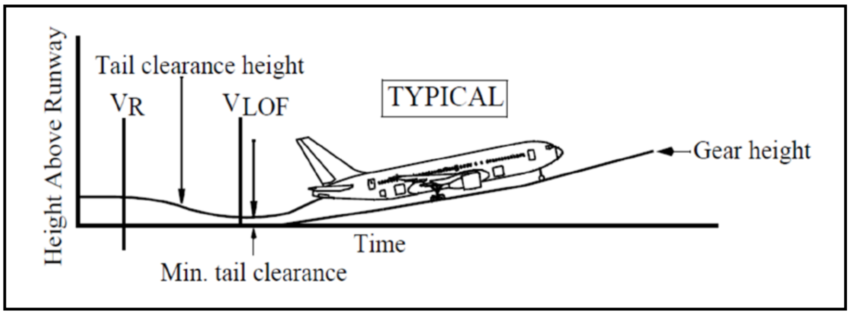


Figure 5

Normal tail clearance profile
(Boeing 787 Flight Crew Training Manual)

Action in the event of a tail contact

The action to be taken in the event of a tail strike being suspected or confirmed (such as the EICAS TAIL STRIKE message), is contained in the QRH. It involves ensuring the aircraft does not pressurise, and the flight crew should plan to land at the nearest available airport. The relevant text is shown at Figure 6 below.

Tail Strike

Condition: A tail strike is suspected or confirmed.

Caution! Continued pressurization of the airplane can cause further structural damage.

1 OUTFLOW VALVE switches (both) . . . . .MAN

Use momentary actuation of the outflow valve manual switches to avoid large and rapid pressurization changes.

2 OUTFLOW VALVE MANUAL switches (both) . . . . Move to OPEN until the outflow valve indications show at the 12 o'clock position to depressurize the airplane

3 Plan to land at the nearest Available Airport.

4 Do **not** accomplish the following checklist:

CABIN ALTITUDE AUTO

■ ■ ■ ■

15.4 Copyright © Qantas Airways Ltd. See title page for details. November 11, 2019

Figure 6

The QRH Tail Strike checklist

Analysis

The aircraft was being operated within its weight, CG and wind limitations for the takeoff. The weather conditions created strong gusting winds which, just before the point of rotation, rapidly increased the aircraft's airspeed from160 KIAS to 175 KIAS. The initial pitch rate of 2°/s increased to 3.2°/s and then 4°/s, when the tail strike prevention system activated and reduced the pitch rate to 2°/s. The lateral control wheel inputs caused the left spoilers to deploy from 5° to 20°, decreasing the lift. The combined effect was that during rotation, an increase in aircraft pitch angle with the main landing gear wheels still on the runway, led to the tail contact angle of 9.7° being reached and the crew receiving an EICAS TAIL STRIKE message.

Having been alerted to the tail contact by the EICAS message, the flight crew actioned the QRH and prevented the aircraft pressurising. After holding, the aircraft was flown to Heathrow in accordance with the checklist.

Conclusion

During conditions of strong, gusty winds, a high pitch rate near lift-off caused the tail strike prevention system to activate. The tail contact angle was reached, and the crew received an EICAS TAIL STRIKE message.

ACCIDENT

Aircraft Type and Registration:	1) Bristell NG5 Speed Wing, G-COLF 2) DH82A Tiger Moth, G-BAFG
No & Type of Engines:	1) 1 Rotax 912ULS piston engine 2) 1 De Havilland Gipsy Major 1F piston engine
Year of Manufacture:	1) 2015 (Serial no: 14045-2762) 2) 1942 (Serial no: 85995)
Date & Time (UTC):	12 July 2020 at 1350 hrs
Location:	Private Strip, Birdsedge, Yorkshire
Type of Flight:	1) Private 2) Private
Persons on Board:	1) Crew - 1 Passengers - 1 2) Crew - 1 Passengers - 1
Injuries:	1) Crew - None Passengers - None 2) Crew - None Passengers - None
Nature of Damage:	1) Wing and tailplane 2) Wing
Commander's Licence:	1) Light Aircraft Pilot's Licence 2) Air Transport Pilot's Licence
Commander's Age:	1) 81 Years 2) 37 Years
Commander's Flying Experience:	1) 1,117 hours (of which 455 were on type) Last 90 days - 16 hours Last 28 days - 8 hours 2) 10,000 hours (of which 3 were on type) Last 90 days - 1 hour Last 28 days - 0 hours
Information source:	Aircraft Accident Report Forms submitted by the pilots

History of the flight

While backtracking, the pilot of G-COLF noticed an area of undulating soft ground across Runway 08 (Figure 1). After turning around at the threshold, he taxied forwards to position beyond the area before starting his takeoff. While crossing the soft ground the aircraft became bogged down and the pilot applied increasingly more power to overcome the resistance. G-COLF's power setting increased to such a level that bystanders thought it was starting its takeoff run. They then saw the nosewheel castor left before the aircraft veered off the runway and collided with G-BAFG on the adjacent grass parking area.

The pilot of G-COLF believed his aircraft may have become stuck in a rut on the runway, leading to the left wheel spat digging into the ground and causing the aircraft to pivot under power. The proximity of G-BAFG to the runway edge meant that the accident pilot had little time to react before the collision.

By their nature, unlicensed airfields can have their own specific hazards that pilots need to be alert to. In this case, parked aircraft near the runway and high power to avoid bogging down in undulating soft ground were catalysts for an accident.

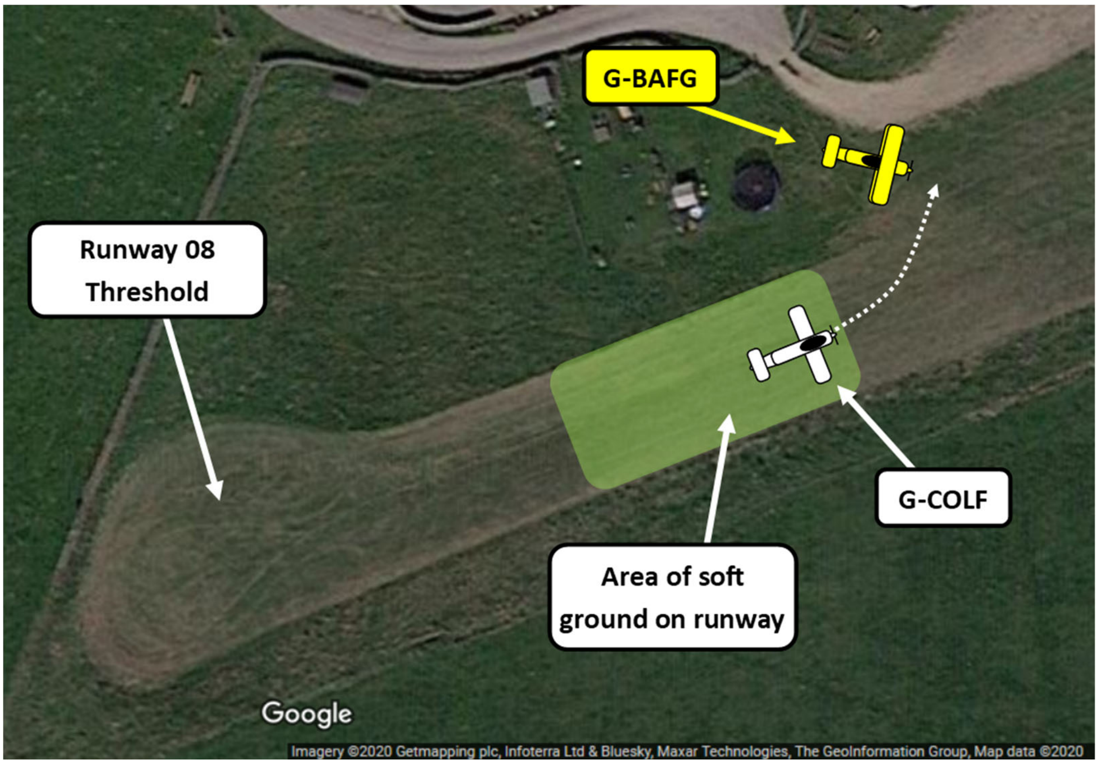


Figure 1

Approximate parked position of G-BAFG and G-COLF's ground track

ACCIDENT

Aircraft Type and Registration:	Jodel DR1051-M1, G-BHTC
No & Type of Engines:	1 Continental Motors Corp O-200-A piston engine
Year of Manufacture:	1964 (Serial no: 581)
Date & Time (UTC):	4 August 2020 at 1430 hrs
Location:	Saltford (Avon Lane) Airfield, Somerset
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - 1
Injuries:	Crew - None Passengers - None
Nature of Damage:	Right wing severed off at crank position. Left wing spar broken
Commander's Licence:	Private Pilot's Licence
Commander's Age:	57 years
Commander's Flying Experience:	1604 hours (of which 1057 were on type) Last 90 days - 9 hours Last 28 days - 8 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot and further enquiries made by the AAIB

Synopsis

The aircraft was approaching touchdown at Avon Lane Airfield when, at 2 m agl, it rapidly rolled to the right. The pilot was unable to regain directional control and hit a nearby hedge. The impact broke the right wing and damaged the fuselage. The pilot made the aircraft safe and he and his passenger vacated uninjured. The probable cause of the accident was the effect of the airfield terrain and the airflow where the grass runway surface levels out after an upslope.

History of the flight

The aircraft was being flown to conduct a series of exercises with an instructor to enable its owner to renew his licence. This included a flight from Compton Abbas to Avon Lane Airfield near Keynsham.

Near Chippenham, the owner handed control to his instructor who was the pilot in command of the aircraft. They had not landed at Avon Lane before, so the instructor joined overhead Runway 27 to survey its suitability for a landing. The wind was estimated at 250º at 10 kt, similar to Compton Abbas and consistent with the forecast. He noted an upslope at the easterly end of the grass runway and anticipated low level turbulence due to the terrain but considered it safe to land. He then flew a left-hand circuit and descended slowly during base leg. As anticipated, the aircraft encountered low level turbulence during the descent. He turned the aircraft onto final approach and aimed to touch down just before the top of the upslope. This was chosen in order to assist the aircraft retardation over the brow and on to the level part of the runway.

However, at about two metres agl, the aircraft rolled 30º to the right and, despite rapid application of stick and rudder, the aircraft contacted the ground and bounced upwards about one metre, and the right main wheel rolled over the left edge of a rubble bank at the side of the runway. Directional control had then been lost and the right wing hit a large bush. The impact broke the outer cranked portion of the right wing off (Figure 1), the aircraft swung to the right and came to a stop. Neither of the crew were injured, the aircraft was made safe and they were able to vacate the aircraft normally. Inspection of the aircraft found that the left main spar, fuselage and propeller had also been damaged.

Figure 1
Damage to the right wing

Discussion

The reason they were flying to this airfield was that the aircraft owner had been planning to keep his aircraft there. His instructor had spoken with the airfield owner prior to the flight and was briefed on the specifics of the airfield and its upslope at the easterly end of Runway 27. He noted that Avon Lane Airfield had some similar characteristics to the one at which he operated his own Jodel. Taking this into account, he considered it safe to operate this aircraft but was clear in his opinion that it requires “good handling skills leaving little room for error”.

In his own analysis as to the cause of the accident he considered that there were several factors as follows;

- The runway is relatively narrow with a difficult approach which requires a high level of concentration.
- The turbulence in the circuit was tolerable, but curlover from the flat portion of the runway caused increased lift from the left wing and hence the right roll.
- The roll took the aircraft off the centre line where it encountered the edge of the bank on the right side of the runway.
- The loss of directional control and the proximity of the hedge meant the landing could not be “rescued”.

AAIB comment

Satellite imagery and open source data show the layout of the airfield. The upslope rises approximately 14 m in 200 m making it a 1:14 (7%) gradient. The location of the bank can be seen, as well as the relative narrowness of the runway. These factors support his assessment that it is a difficult approach and requires a lot of concentration.

ACCIDENT

Aircraft Type and Registration:	Pietenpol Air Camper, G-BWVB
No & Type of Engines:	1 Continental Motors Corp O-200-A piston engine
Year of Manufacture:	1997 (Serial no: PFA 047-11777)
Date & Time (UTC):	24 August 2020 at 1610 hrs
Location:	Loadman Farm, Hexham, Northumberland
Type of Flight:	Private
Persons on Board:	Crew -1 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Damage to landing gear, propeller and airframe
Commander's Licence:	Private Pilot's Licence
Commander's Age:	56 years
Commander's Flying Experience:	474 hours (of which 8 were on type) Last 90 days - 6 hours Last 28 days - 2 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

Synopsis

Following the pre-takeoff power checks, which were carried out normally, the pilot lined up on the runway and increased power for takeoff. The aircraft accelerated along the runway and, as the tail came up, the pilot noticed that the ground roll was longer than usual. Shortly after lift-off, the engine lost power and the aircraft struck a bund with a fence on top, shearing off the landing gear and tipping the aircraft onto its back.

History of the flight

The aircraft had been flown on several flights since its overwinter layup in the hangar and had an engine oil filter and oil change immediately before the accident flight. The aircraft was pre-flight checked and, although the top fuel tank was empty, the main tank held enough fuel for the intended flight. The engine started normally, and the pilot taxied to the threshold of Runway 28. The runway is 425 m long with a short grass surface and a slight uphill incline in the takeoff direction. The weather was good with surface wind from 340° at 5 kt, CAVOK and an OAT of 12°C.

The pilot positioned the aircraft near the runway threshold and stopped the engine, switching off the magnetos and the electrical master switch. He then carried out a check for oil leaks following the earlier maintenance work. No leaks were found, the aircraft was started, and power, magneto and carburettor heat checks were carried out.

The pilot noticed that the surface wind had veered to the north, but conditions were still suitable for departure.

He lined up on the runway, ensured that the electric fuel pump was ON, increased the power to maximum and the aircraft accelerated. As the speed increased, the pilot lifted the tail but noticed that the ground roll was longer than usual. He confirmed the carburettor heat control was in and at that moment the aircraft lifted off. At approximately 30 ft, the engine suddenly lost all power.

The pilot lowered the nose but realised he did not have enough runway left to land safely or enough energy to clear the small bund at the edge of the field, which had a stock fence running along the top. He continued the descent, noting the ASI was reading just below 50 kt, and touched down approximately 10 m before the edge of the field. The aircraft struck the bund and fence, which sheared off the landing gear and caused the aircraft to nose over onto its back. The pilot was wearing a four-point harness and, noticing the fuel was leaking out of the main tank, released himself and vacated the aircraft, returning momentarily to switch off the fuel and electrical systems.

Discussion

Given that the engine power, magneto and carburettor heat checks were normal, the pilot considered that there had been no indication of any abnormality that would lead to the eventual loss of power. He thought that some type of fuel contamination may have been possible but the fuel had drained out whilst the aircraft was inverted on the ground so this could not be tested. After the aircraft had been recovered, the inside of the fuel tank was inspected with a borescope, but no evidence was found that may have related to fuel contamination. Incorrect fuel tank selection or switching off the fuel pump inadvertently after restarting the engine were possibilities, but he considered both unlikely because he had turned them all off when he returned to the cockpit.

ACCIDENT

Aircraft Type and Registration:	Pioneer 300, G-CDSD
No & Type of Engines:	1 Rotax 912ULS piston engine
Year of Manufacture:	2005 (Serial no: PFA 330-14439)
Date & Time (UTC):	9 June 2020 at 1200 hrs
Location:	Wallis International Airstrip, Peterborough
Type of Flight:	Private
Persons on Board:	Crew - 2 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Damage to the engine and airframe
Commander's Licence:	Private Pilot's Licence
Commander's Age:	49 years
Commander's Flying Experience:	131 hours (of which 36 were on type) Last 90 days - 2 hours Last 28 days - 2 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

Synopsis

The aircraft bounced on touchdown and landed back on the left side of the runway. The left wing became caught in long grass and the aircraft yawed left, veering off the runway and dropping into a dyke where it came to a halt.

History of the flight

The pilot flew from a private farm strip east of Alconbury Airfield to Wallis International Airstrip near Whittlesey. The weather was good; CAVOK and light winds. The transit was uneventful and, on arrival, the pilot flew a normal approach to Runway 08, but with a planned go-around to check the runway before landing. The high trees near the Runway 08 threshold were noted, as was the direction of the wind, which was from the east and down the runway. A second approach was made but, due to other traffic, another go-around was flown.

The third approach was commenced with full flap selected on finals, and with an approach speed of 65 KIAS reducing to 50-55 KIAS over the threshold. The need to ensure a safe margin over the trees caused the aircraft to touch down approximately half-way along the 770 m grass strip where it went over a bump, causing it to bounce and land back on the left side of the runway. The pilot applied the wheel brakes but the left wing became caught in long grass and the aircraft yawed to the left, veering off the runway and striking several concrete posts and barbed wire fencing. It dropped into a water filled dyke on the north side of the runway and the canopy detached, with the aircraft remaining upright. The pilot and passenger were uninjured and were able to vacate the aircraft unassisted.

The pilot considered that a lack of experience of landing on a farm strip with obstacles, such as the trees close to the threshold, had caused the aircraft to touch down further into the runway than expected. Encountering the bump in the runway surface and touching down close to the left edge of the runway led to the left wing entering the long grass.

SERIOUS INCIDENT

Aircraft Type and Registration:	Piper PA-38-112, G-BPPF
No & Type of Engines:	1 Lycoming O-235-L2C piston engine
Year of Manufacture:	1979 (Serial no: 38-79A0578)
Date & Time (UTC):	6 September 2020 at 1605 hrs
Location:	Compton Abbas Airfield, Salisbury
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	None
Commander's Licence:	Private Pilot's Licence
Commander's Age:	54 years
Commander's Flying Experience:	202 hours (of which 57 were on type) Last 90 days - 4 hours Last 28 days - 1 hour
Information Source:	Aircraft Accident Report Form submitted by the pilot

The pilot was visiting Compton Abbas Airfield and, having taxied out for departure, proceeded to line up on what he thought was the runway. He had actually lined up to the left of the runway. During the takeoff roll, the aircraft pulled to the left, which was subsequently diagnosed as a binding left brake. This, combined with his starting position, meant he got close to a line of parked aircraft. The pilot described that he lined up to the right of what looked like two 'black cones'.

The UK Aeronautical Publication (AIP)[1] page on Compton Abbas details the runway markings which include black and white runway threshold markers positioned to the side of the runway threshold. Figure 1 is an image from Google Earth showing the boards and the chalk marked runway. The pilot of G-BPPF probably lined up between the marker board and the left side chalk line of the runway.

It is the AIP that contains validated aviation data, but image tools can be extremely useful to pilots who are visiting places that they may not be familiar with. Whilst they do not provide detailed, up to date information, they can add a visual image of what to expect.

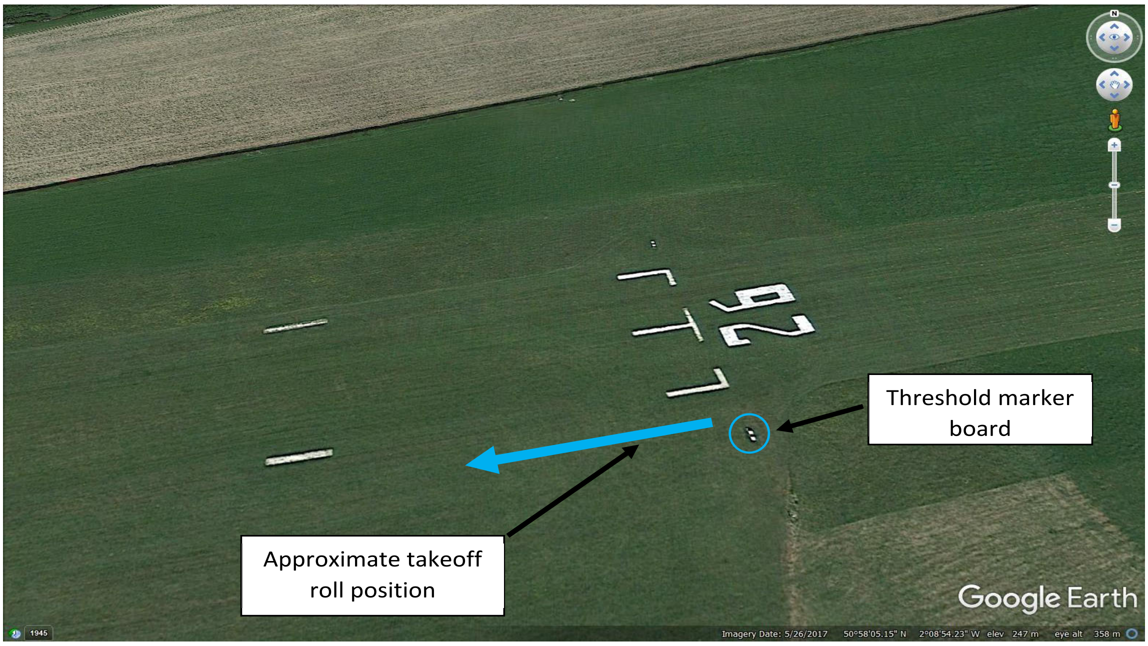


Figure 1

Runway 26 threshold showing the marker board and the approximate takeoff roll of G-BPPF

SERIOUS INCIDENT

Aircraft Type and Registration:	Reims Cessna F150M, G-CSBM
No & Type of Engines:	1 Continental Motors Corp O-200-A
Year of Manufacture:	1977 (Serial no: 1359)
Date & Time (UTC):	10 July 2020 at 1438 hrs
Location:	Winchfield, Hampshire
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - 1
Injuries:	Crew - None Passengers - None
Nature of Damage:	None
Commander's Licence:	Private Pilot's Licence
Commander's Age:	24 years
Commander's Flying Experience:	215 hours (of which 103 were on type) Last 90 days - 23 hours Last 28 days - 17 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot and further enquiries by the AAIB

Synopsis

As the aircraft approached Blackbushe Airport the engine lost power and the pilot made a precautionary landing in a field. There was no damage to the aircraft and neither occupant was injured.

The engine lost power due to fuel exhaustion. The pilot had used a fuel dipstick through a desire to measure the fuel onboard more accurately, but the dipstick used was not calibrated for the aircraft; this led him to overestimate the fuel onboard.

History of the flight

The pilot and a friend planned to fly a return trip from Blackbushe Airport (Blackbushe) in Hampshire to Sandown Airport (Sandown) on the Isle of Wight. He was aware that with the two people on board he could not completely fill the fuel tanks as this would put the aircraft above its maximum takeoff weight. He had calculated that he required 16 US gal of fuel for the return trip which included 5 US gal of reserve fuel. Prior to departing from Blackbushe the pilot checked the fuel quantity onboard with a dipstick. There was a wooden dipstick in the aircraft which was marked with a 0, ¼, ½, ¾ and full scale but the pilot found it difficult to see the fuel level on the stick and he wanted a more accurate measurement. Therefore, he found a dipstick which was marked with a more detailed scale, that was easier to read and was similar to one he had previously used on the Cessna 150. Using this he determined there was 9-10 US gal in each tank which he believed was sufficient for his intended trip.

The flight from Blackbushe to Sandown was uneventful. On the ground in Sandown the pilot re-measured the fuel quantity in each tank using the same dipstick. This showed there was 3-4 US gal in one tank and 9-10 US gal in the other. He was surprised that the tanks were not balanced so contacted another pilot who advised that this was not abnormal for this aircraft type. He was confident he had enough fuel for the return flight plus reserves, so did not refuel.

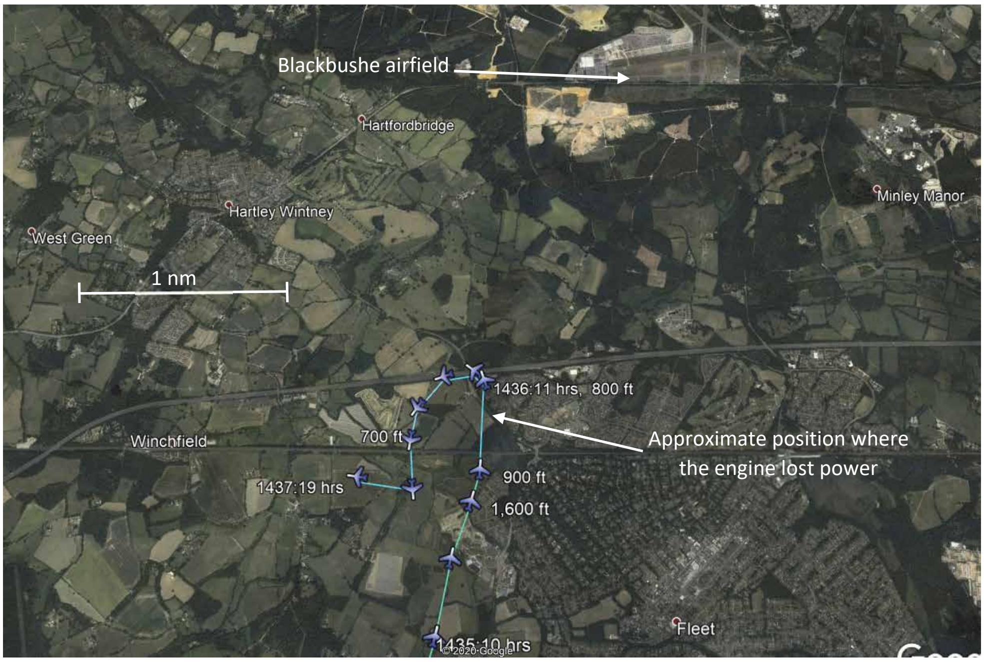


Figure 1

Aircraft track approaching Blackbushe Airport

The pilot had been trained that the fuel gauges on light aircraft are unreliable, and so did not use them.

The return flight was uneventful until the aircraft was approximately 2 nm from Blackbushe. The pilot had just descended to circuit height when the engine started to cough and lose power. He did not know what was wrong with the engine but, being aware that landing options close to the airport were limited if the engine failed completely, he decided the safest option was to make a precautionary landing in a field. He selected a large grass field on his left side and made an 180° turn to position the aircraft on a base leg for the field (Figure 1). The engine continued to run but was still losing power. He landed in the field using full flap and stopped the aircraft (Figure 2). There was no damage to the aircraft and both occupants were uninjured.

After landing no fuel could be seen visually in either fuel tank. It was subsequently discovered that the dipstick the pilot had used was calibrated for a Cessna 172 so showed a greater quantity of fuel than was actually present.

Figure 2
G-CSBM after the precautionary landing

Flying club comment

The owner of the flying club commented that whilst pilots are trained not to rely on the fuel gauges in light aircraft the gauges on G-CSBM are reasonably accurate.

After the incident he sent a message to all pilots at the club reminding them that the fuel dipsticks are different in each aircraft type and to ensure they use the one calibrated for the aircraft they are flying.

The flying club uses an electronic aircraft log, so it is not possible for pilots to see when the aircraft was last refuelled and how much flying the aircraft has done since. The owner reported that this was intentional to ensure pilots did not rely on this information and instead measured how much fuel was onboard before each flight.

Aircraft information

The Cessna 150 has two interconnected fuel tanks, one in each wing. Fuel is gravity fed to the engine (Figure 3). The tanks can hold 26 US gal of fuel but 3.5 US gal is unusable, giving a total usable capacity of 22.5 US gal.

Although the fuel tanks are interconnected, it was reported that it is not uncommon for the fuel to be imbalanced after flight. This can be caused by several banked turns in the same direction prior to landing causing the fuel to migrate to one side.

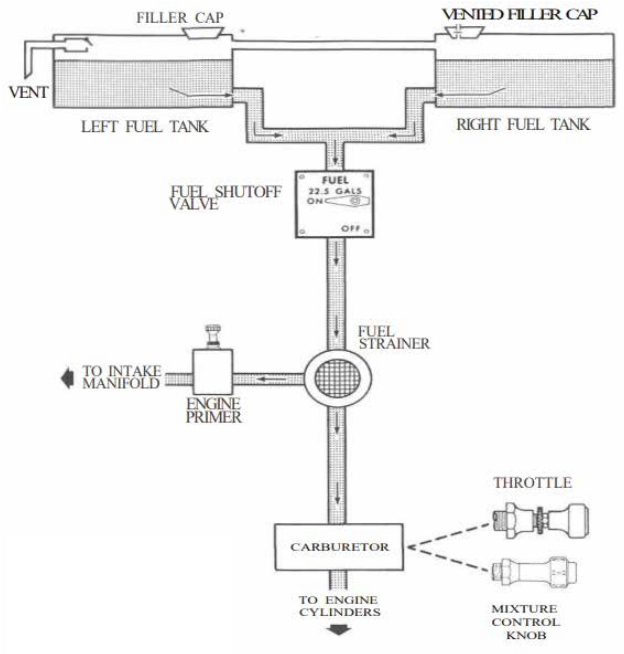


Figure 3

Cessna 150 fuel system

Weight and balance

The Cessna 150 maximum takeoff weight is 1,600 lbs (726 kg). G-CSBM basic weight was 526 kg. The pilot calculated that on takeoff from Blackbushe, with 54 kg of fuel and with a combined occupant weight 152 kg, the aircraft weighed 732 kg.

Fuel planning and management guidance

The CAA skyway code (CAP 1535S[1]) states that:

> *'Fuel gauges in most general aviation aircraft are not very accurate and should not be considered a reliable indicator of fuel level. You should physically check fuel levels on the ground by dipping the fuel tanks.'*

Following several fuel starvation and fuel exhaustion accidents in New Zealand the Civil Aviation Authority of New Zealand published a guidance document titled '*Fuel Management*'[2]. The document contains the following guidance:

> *'It's good practice to check the fuel available before flight by at least two separate methods. We can do this by referring to the fuel gauge(s), loading a known quantity and, in many aircraft, by dipping the tanks.*

Footnote

1 CAA, '*The Skyway Code*' available at https://publicapps.caa.co.uk/modalapplication.aspx?appid=11&mode=detail&id=7920 (accessed 3 August 2020).

2 Civil Aviation Authority of New Zealand, '*Fuel Management*' available at https://www.aviation.govt.nz/assets/publications/gaps/Fuel_Management.pdf (accessed 3 August 2020).

Using a fuel dipstick is the most accurate way of determining the fuel on board. It's therefore important to ensure that you have the correct dipstick for your aircraft. Each dipstick has been specifically calibrated to the fuel tanks of a particular aircraft and is therefore not interchangeable with those of any other aircraft, even of the same type – which is why it should be clearly marked with the aircraft registration and also show whether the figures are total or usable fuel.

Keep an accurate fuel log. This, in combination with fuel gauge readings, is an important part of monitoring your fuel status in flight. The bottom line is that every method and aid you have for monitoring fuel quantity should be used. Remember to keep a close eye on the fuel gauge. Some pilots dismiss gauges as unreliable. That's possibly unwise, considering the number of fuel starvation or exhaustion incidents where pilots have pressed on with low gauge readings. Make regular reading of fuel gauges an integral part of your fuel management strategy.

If, despite doing this, your fuel situation becomes critical […] *then a precautionary landing is the best course of action. Too many accidents have occurred because pilots pressed on thinking that they could make it. The fact that the aircraft may be damaged in a precautionary landing should not influence the decision – aircraft can always be repaired. It's human nature that, when faced with marginal situations, we feel the pressure to reach our intended destination. "My passengers need to get to the destination today"; "the aircraft has to be back tomorrow"; "I don't want anyone to know that I stuffed up"; are the types of thoughts that usually run through our minds. Ignore them, and take decisive action to divert, or land.'*

Analysis

As the aircraft approached Blackbushe Airport the engine lost power due to fuel exhaustion. The pilot's decision to make a precautionary landing in a field produced a safe outcome.

The fuel exhaustion occurred because, before the flight, the pilot had measured the fuel with a dipstick which was calibrated for another aircraft type. Consequently, he thought there was more fuel onboard than was actually present. The pilot wanted to measure it as accurately as possible to ensure he had enough for his intended journey but also to remain below the aircraft's maximum takeoff weight. The desire for a more accurate reading led him to use a fuel dipstick which he thought was more accurate. The accident highlights the importance of checking the dipstick is calibrated for aircraft being flown.

The pilot did not use the fuel gauges on the aircraft in flight as he believed them to be unreliable. However, the aircraft owner reported that on this aircraft the gauges are accurate. Many guidance documents stated that fuel gauges on light aircraft can be unreliable, but, as highlighted in the New Zealand CAA guidance, this does not mean that they should not be used at all. Fuel gauges can be used as part of an overall fuel management strategy. In this event it is likely that the fuel gauges would have indicated the low fuel state.

The New Zealand CAA guidance recommends checking the fuel onboard by two independent means. One means of estimating the fuel onboard is checking the total flight time since the aircraft was last fuelled to a known state. This can usually be determined from the aircraft's log. The flying club which operated G-CSBM used an electronic log system that did not enable the pilot to see the previous flights. This removed one possible barrier which might have alerted the pilot to the incorrect fuel measurement.

When the engine began to lose power the pilot decided to make a precautionary landing. The pilot's decision to land before the engine stopped completely gave him time to position the aircraft into a suitable large field and focus on flying the aircraft to ensure a safe outcome.

Conclusion

The pilot made a safe precautionary landing in a field due to loss of engine power. The engine had lost power due to fuel exhaustion.

Through a desire to measure the fuel accurately the pilot had used the incorrect fuel dipstick leading him to overestimate the fuel onboard.

Safety action

The flying club have reminded pilots of the importance of only using the dipstick calibrated for the aircraft they are flying.

ACCIDENT

Aircraft Type and Registration:	Replica WAR FW190, G-CCFW
No & Type of Engines:	1 Continental Motors Corp O-200-A
Year of Manufacture:	2003 (Serial no: PFA 081-12729)
Date & Time (UTC):	12 July 2020 at 1350 hrs
Location:	Lower Upham Farm Airstrip, Marlborough, Wiltshire
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - 1 (Serious) Passengers - N/A
Nature of Damage:	Extensive damage to propeller, engine, fuselage, fin and rudder
Commander's Licence:	National Private Pilot's Licence
Commander's Age:	82 years
Commander's Flying Experience:	12,617 hours (of which 413 were on type) Last 90 days - 4 hours Last 28 days - 2 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

Synopsis

The aircraft landed in a field adjacent to the grass airstrip. The aircraft pitched over after landing, trapping the pilot. The aircraft was extensively damaged and the pilot suffered serious injuries.

History of the flight

The pilot was flying G-CCFW, a Replica WAR FW190. The skies were clear with bright sunshine and light winds from the southwest. At around 1200 hrs, the pilot returned to the airstrip to land on its southerly runway. On landing, the aircraft travelled a short distance when it "stopped violently" and pitched over onto its back, trapping the pilot. The pilot was removed from the aircraft by emergency services and had suffered serious injuries. The aircraft was damaged extensively and deemed uneconomic to repair.

Analysis

The aircraft had landed in crop to the left of the grass runway. He reported that he mistook the unmarked grass runway to be part of the crop in the adjacent field to the right of the runway owing to its similarity in colour (Figure 1). Instead, he made an approach to and landed in the field to the left of the runway, where tractor marks and the edge of the grass airstrip had created the appearance of a 'false' runway similar in size and shape. The sun overhead may have reduced the contrast between the grass strip and the crops, contributing to the reduced conspicuity of the grass airstrip.

The pilot reported that the runway has since been marked out with white chalk lines.

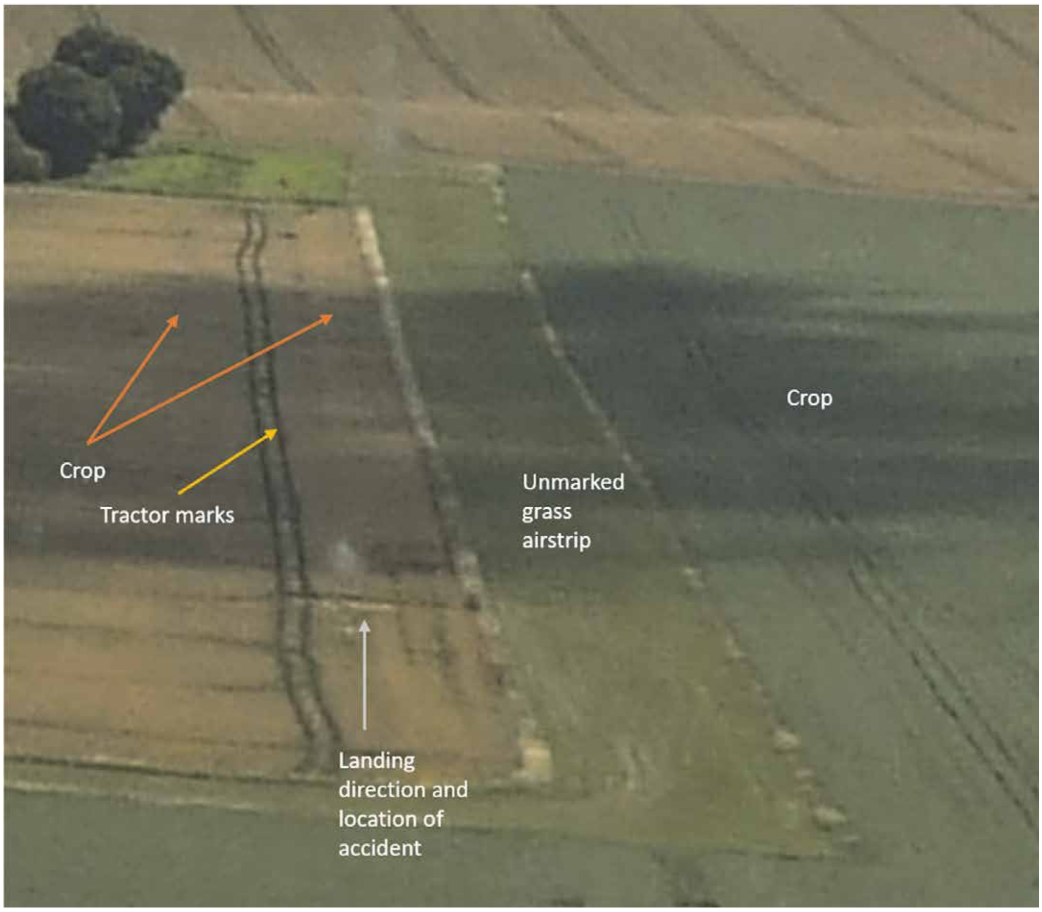


Figure 1

The approach to the grass airstrip;
(picture taken the following day)

ACCIDENT

Aircraft Type and Registration:	Robinson R44 Raven II, G-WTWT
No & Type of Engines:	1 Lycoming IO-540-AE1A5 piston engine
Year of Manufacture:	2019 (Serial no: 14294)
Date & Time (UTC):	26 July 2020 at 0904 hrs
Location:	Herne Bay, Canterbury, Kent
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - 3
Injuries:	Crew - 1 (Minor) Passengers - 2 (Minor)
Nature of Damage:	Substantial
Commander's Licence:	Private Pilot's Licence
Commander's Age:	53 years
Commander's Flying Experience:	400 hours (of which 268 were on type) Last 90 days - 3 hours Last 28 days - 1 hour
Information Source:	Aircraft Accident Report Form submitted by the pilot and further enquiries by the AAIB

Synopsis

Shortly after takeoff, the pilot realised that the left front door was not properly closed so decided to make a precautionary landing. During the approach the helicopter developed a high rate of descent which the pilot was not able to arrest. The helicopter stuck the ground and rolled over. Three of the occupants sustained minor injuries.

The investigation found the helicopter had made a downwind approach to land and was likely to have entered a vortex ring state. The pilot was not aware he was making a downwind approach.

History of the flight

On the day of the accident the pilot planned to fly the helicopter to a friend's house with his wife and two other friends. On arrival the intention was then to take his friend and their two daughters on a short local flight.

The first flight from Orsett near Thurrock, where the helicopter is kept, to his friend's house near Herne Bay was uneventful (Figure 1). The landing site was located close to Maypole airfield. The pilot had contacted the owner of the airfield the day before and had been advised to make blind calls on the airfield frequency and to remain west of the centreline for noise abatement. The pilot overflew the landing site from the south-west and flew an orbit of the field. The wind was from the south-west so he made a crosswind approach to the field to remain west of Mayfield. He made blind calls on the frequency but did not hear or see any other traffic.

Figure 1

GPS track of first flight and accident flight
© 2020 Google, Image © SIO, NOAA, U.S. Navy, NGA, GEBCO)

After landing the pilot wound the throttle back to idle but kept the rotors running. The three passengers exited the helicopter whilst the pilot remained at the controls. His friend and their two daughters then boarded the helicopter. The pilot's wife and other friend assisted them getting in and helped them with their seatbelts and headsets. Once the three new passengers were onboard and everyone was clear the pilot took off to the west.

The pilot climbed to 400 ft tracking to the north to remain clear of Maypole. As they were climbing away the pilot noticed that the left front door was not fully closed. There was approximately a half inch gap between the door and the frame. The latch appeared to be in the rear (closed) position but not rotated down. He asked the passenger to push the handle down but it would not move. He then asked the passenger to pull the door inwards and to try to latch it but he inadvertently unlatched the door and it opened 1 to 2 inches which alarmed the passenger. At this stage the pilot decided to make a precautionary landing in a field so he could close the door on the ground.

The pilot selected a suitable large field ahead. He believed he was still heading north and planned to make a crosswind approach on his current heading then turn left into wind when he was lower.

The pilot lowered the collective and established the descent. In the bottom third of the descent the pilot raised the collective to reduce the descent and tried to turn left with the cyclic. However, the helicopter did not turn. As the helicopter descended through 50 ft the pilot tried harder to turn and pulled more and more collective to reduce the rate of descent, but it did not have any effect. The engine appeared to be running and there were no warning lights or unusual vibration.

The helicopter stuck the ground with the right skid first. The skid dug in and the helicopter rolled onto its right side (Figure 2). The pilot and front seat passenger were able to climb out of the left front door and helped the two rear seat passengers exit. Emergency services arrived shortly afterwards.

The pilot and two of the passengers had minor injuries.

Figure 2

G-WTWT after the accident

After the accident, the pilot realised he had inadvertently turned right whilst trying to resolve the door problem and had made the approach track tracking north-east. He thought a possible reason for him being unable to turn was that the passenger may have inadvertently restricted the controls as the dual controls were still fitted. However, the passenger was not aware of having done this.

Accident site

Figure 3 shows the initial impact mark where the right skid dug into the soil causing the helicopter to roll over.

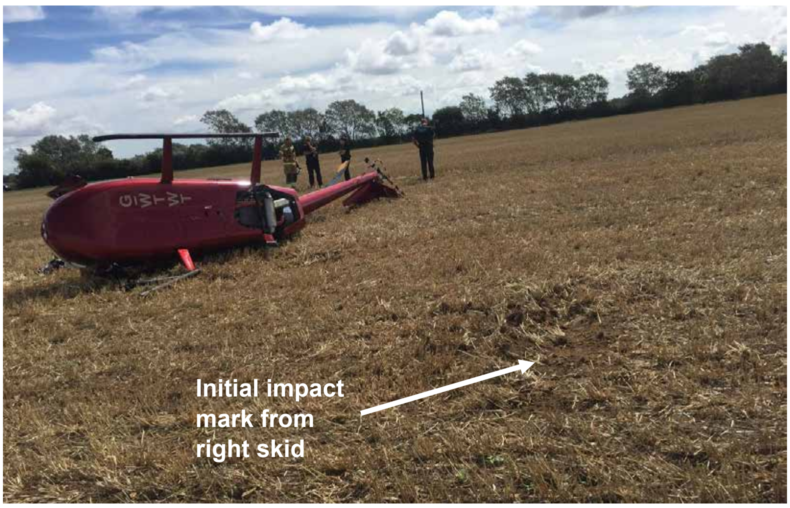


Figure 3

Accident site showing the initial impact mark from the right skid

Meteorology

The general weather conditions in the region at the time of the accident were good. The visibility was greater than 10 km, cloud was scattered at approximately 2,000 ft and the temperature was 18°C.

The surface wind reported at Southend Airport (38 km north-west of accident site) was from 240° at 14 kt at 0850 hrs and from 250° at 10 kt at 0920 hrs. At 0900 hrs the surface wind at Shoeburyness (30 km south-west) was from 270° at 11 kt and at Manston (15 km east) it was from 240° at 12 kt.

The UK low-level spot wind chart forecast the 1,000 ft wind in the region to be from 260° at 20 kt (between 0300 hrs and 0900hrs) and from 270° at 20 kt (between 0900 hrs and 1500 hrs).

Recorded information

The pilot was using a flight planning and navigation app on a tablet computer which recorded the accident flight. Figures 4 and 5 show the helicopter's track downloaded from the tablet. The orbit around the first landing site can be seen in the figures to the west of Mayfield. The helicopter reached a GPS altitude of 746 ft above the landing field elevation.

Figure 6 shows the data extracted. The helicopter's heading as it approached the ground was approximately 070°. The groundspeed reached a maximum of 107 kt then reduced steadily during the descent. Table 1 shows the helicopter's rate of descent, groundspeed and estimated airspeed as it descend below 100 ft. The airspeed has been estimated assuming a 10 kt tailwind.

Height above the ground (ft)	Ground-speed (kt)	Estimated airspeed (kt)	Derived Rate of descent (ft/min)	Heading (degrees)
98	31	21	914	070
78	26	16	1,186	070
58	23	13	1,192	069
36	21	11	1,344	066
14	19	9	1,271	064

Table 1

GPS data as the helicopter descended through 100 ft

Figure 4

Accident flight showing altitude profile
(© 2020 Google, Image © SIO, NOAA, U.S. Navy, NGA, GEBCO)

Figure 5

Accident flight ground track orientated north up
(© 2020 Google, Image © SIO, NOAA, U.S. Navy, NGA, GEBCO)

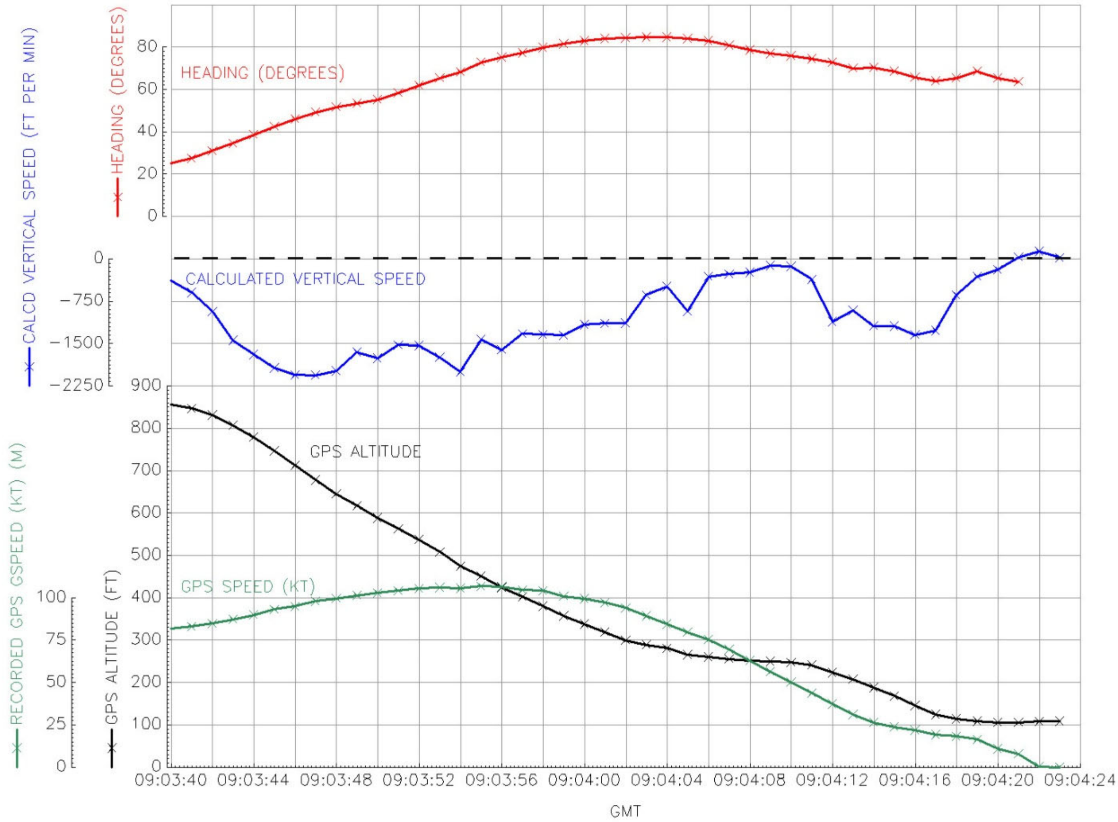


Figure 6

GPS data from last part of accident flight

Vortex ring state[1]

Vortex ring state describes an aerodynamic condition which results in a sudden loss of rotor thrust and a subsequent rapid loss of height.

Although vortices are always present around the periphery of the rotor, under certain airflow conditions the vortices will intensify and, coupled with a stall spreading outwards from the root end of the blade, result in a sudden loss of rotor thrust. This is known as a vortex ring state. It can be entered from several inflight manoeuvres but the airflow conditions which cause it remain substantially the same. It will only occur when all the following are present:

- Power is applied to the rotor (giving an induced flow down through the rotor disc),
- There is a high rate of descent (giving an external airflow opposing the induced flow),
- The indicated airspeed is low.

Footnote

1 Bailey, N. (2008) The helicopter pilot's manual: Principles of flight and helicopter handling. Marlborough: Airlift Publishing.

All times are UTC

These conditions can occur whilst making a downwind approach. If the rate of descent is too high and the airspeed is allowed to reduce significantly the helicopter can encounter vortex ring.

Once in a vortex ring state the controls become significantly less responsive due to the reduced length of rotor blade that is producing thrust and therefore able to respond to control inputs.

Analysis

Shortly after takeoff the pilot became aware that the left front door was not fully closed. The passenger was unable to close the door in flight so the pilot made the decision to make a precautionary landing. Whilst trying to instruct the passenger to close the door the pilot did not notice that the helicopter had turned to the east and was heading downwind. The pilot did not realise that he was making a downwind approach to the field.

As the helicopter descended below 100 ft the rate of descent was greater than 1,000 ft/min and the airspeed dropped below 15 kt. It is likely that the helicopter started to enter a vortex ring state. This would explain why the helicopter did not respond to increasing collective and did not turn left with cyclic input. The pilot did not recognise the helicopter was entering vortex ring so did not apply corrective action.

The pilot suggested that it is also possible that the passenger had inadvertently restricted the controls as the dual controls were still fitted.

The accident highlights the hazard of passengers boarding with rotors running where it is harder for the pilot to confirm all doors are properly closed. It also demonstrates how easy it is for a pilot to be distracted from the primary task of flying the aircraft when a minor problem occurs in flight.

Conclusion

The pilot decided to make a precautionary landing when he became aware that a door was not properly closed. However, he inadvertently made a downwind approach. During the later stage of the decent it is likely that the helicopter started to enter a vortex ring state leading to a high rate of descent which the pilot was not able to arrest.

ACCIDENT

Aircraft Type and Registration:	Easy Raider 503(1), G-SRII
No & Type of Engines:	1 Rotax 503-DCDI-2V piston engine
Year of Manufacture:	2001 (Serial no: BMAA/HB/163)
Date & Time (UTC):	12 July 2020 at 1320 hrs
Location:	Near Dunnington, York
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - 1 (None) Passengers - N/A
Nature of Damage:	Engine seized, damage to propeller, landing gear, tail and fuselage
Commander's Licence:	National Private Pilot's Licence
Commander's Age:	53 years
Commander's Flying Experience:	212 hours (of which 116 were on type) Last 90 days - 4 hours Last 28 days - 4 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot and additional enquiries by the AAIB

Synopsis

The aircraft made a successful forced landing in a crop field following an engine seizure and associated loss of engine power. The pilot had inadvertently omitted to add two-stroke oil to the fuel when preparing for the flight and the engine seized due to a lack of sufficient lubrication.

History of the flight

The pilot had planned to fly from Baxby-Hustwaite Airfield, North Yorkshire, where his aircraft was based, to Sturgate Airfield in Lincolnshire, and back again. The Easy Raider is a high-winged, two-seat microlight aircraft powered by a two-stroke Rotax 503 engine. Prior to departing, he prepared two 20 litre jerry cans of Mogas (motor gasoline) by adding a measured dose of two-stroke oil. He used one can to fill the aircraft's wing fuel tanks and secured the other in the aircraft, to be used for the return leg. The outbound flight was uneventful. Prior to departing Sturgate for the return leg, the pilot topped-up the fuel tanks using the jerry can he had brought with him. He did not have a step ladder and so filled the tanks by reaching up from the ground.

Approximately 40 minutes into the return flight, as the aircraft was cruising at 1,800 ft agl, the engine started to run rough and subsequently seized, resulting in a total loss of engine power. The pilot declared a MAYDAY and selected a suitable field in which to land. The pilot completed a successful forced landing in a crop field and was uninjured, exiting the aircraft without assistance, but the aircraft sustained substantial damage due to the furrowed surface of the field (Figure 1). After landing, he examined the unused fuel in the jerry can and discovered that there was no evidence of the dye he would have expected to see if two-stroke oil had been present in the fuel.

Figure 1
G-SRII after landing

Pilot's comments

Fuel was not permitted in the hangar where the aircraft was kept, so when preparing the Mogas prior to the flight, the pilot left the jerry cans outside. He measured out the two-stroke oil in the hangar, returning to the fuel cans each time to add the oil. Although each jerry can was a different colour, he subsequently realised that he must have experienced a lapse in concentration while doing this, which resulted in him adding both doses of oil to the first can, and none to the second.

This was the first time the pilot had prepared two identical volumes of fuel in jerry cans. He would normally fuel the aircraft directly from the fuel supply at the airfield and only prepare one jerry can to carry in the aircraft.

The pilot stated that in future he would add the two-stroke oil as he poured the fuel into the aircraft fuel tanks. If he did need to prepare a jerry can in advance, he would take the oil to the fuel cans, rather than measure it out in the hangar.

He also considered that when fuelling the aircraft prior to the return flight, doing so from below meant he did not have the opportunity to see the colour of the fuel and observe that it did not contain any two-stroke dye.

When asked what factors had contributed to the successful outcome of the forced landing, the pilot said that as a microlight pilot he was always aware that an engine failure can occur at any time, especially with a two-stroke engine. It was therefore his custom to regularly consider potential landing sites and how far he could glide from his present position, as part of his checks throughout a flight.

The pilot's licence had expired the previous autumn and he was unable to renew it for about eight months. Several days before the accident, he had undertaken a General Skills Test (GST) in another aircraft to renew his licence. The next day he flew for approximately one hour in G-SRII at his home airfield to ensure he was current, in anticipation of undertaking a longer flight. In preparation for his GST he had revised the forced landing procedure and associated decision making. He also watched several videos about choosing a suitable field for a forced landing and one relating to field landings for glider pilots.

The pilot considered that the handling qualities of the aircraft, his routine checking for potential landing sites and the preparation undertaken for his recent GST were all factors which contributed to the successful outcome.

Conclusion

The engine seized in flight due to a lack of sufficient lubrication. When preparing for the flight the pilot inadvertently omitted to add two-stroke oil to the aircraft's fuel. The manner in which the fuel was added to the aircraft prevented him from detecting the absence of the two-stroke oil. The pilot completed a successful forced landing because his training and practice enabled him to identify a suitable landing site within the gliding capability of the aircraft.

ACCIDENT

Aircraft Type and Registration:	Tecnam P92-EM Echo, G-WHEN
No & Type of Engines:	1 Jabiru 2200A piston aero engine
Year of Manufacture:	2004 (Serial no: PFA 318-13679)
Date & Time (UTC):	23 June 2020 at 13:00 hrs
Location:	Lleweni Parc Denbigh Airfield, Denbigh
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Propeller broken, left wing dented and displaced
Commander's Licence:	National Private Pilot's Licence
Commander's Age:	73 years
Commander's Flying Experience:	780 hours (of which 700 were on type) Last 90 days - 2 hours Last 28 days - 2 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot and enquiries made by the AAIB

Synopsis

After an eventful flight in marginal weather conditions, the aircraft was being taxied back to the hangar when its left wing collided with a telehandler which was parked next to the taxiway. The aircraft sustained damage to its wing and propeller.

History of the flight

The pilot reported that he intended to fly to a nearby airfield and that when he departed the cloud base was obscuring the high ground. He also stated that as a result of the low cloud he became disorientated and lost; moreover, his engine started to run roughly, and he "anticipated" that he might need to carry out a forced landing. However, the engine continued running and he returned to the airfield and landed.

Whilst taxiing back to the hangar, the left wing struck a stationary telehandler parked alongside the taxiway. The aircraft pivoted to the left and came to a stop wedged against the telehandler (Figure 1). The impact dented the left wing leading edge near the wing tip, displaced the wing and distorted the flap. The propeller was severely damaged, and the lower engine cowl was dented. The pilot and a construction worker, who was standing close to the telehandler at the time, were uninjured.

Figure 1
Aircraft and telehandler following the collision

Telehandler position and taxiway topography

The lime green coloured telehandler was parked perpendicular to the tarmac taxiway, at the edge of an area of hard ground, in front of a newly constructed low hangar. A taxiway widening strip, referred to as a 'ditch', ran alongside the taxiway on the opposite side to where the telehandler was parked. The ditch had a smooth unfinished surface which had been added to widen the taxiway to allow glider wings to pass the building site. It was about 100 mm lower than the taxiway surface and had chamfered edges.

Collision with the telehandler

Just prior to the collision, the aircraft was being taxied towards the left side of the telehandler putting the ditch on the right side of the aircraft.

The pilot described how he allowed the right main wheel to run into the ditch to make room to pass the telehandler. In his opinion, it was the wheel running in the ditch that caused the aircraft to swing around to the left and into the telehandler.

Individuals who responded to the collision commented that there was a dent on the left leading edge consistent with the outer section of the left wing contacting the telehandler, causing the aircraft to swing to the left and hit the main body of the vehicle.

AAIB comment

The series of events during the flight would have been very stressful for the pilot. It is possible that his relief, at landing safely, resulted in a lapse in concentration as he taxied to the hangar, such that there was insufficient wingtip clearance between the aircraft and telehandler.

ACCIDENT

Aircraft Type and Registration:	DJI Inspire 2, (UAS, registration n/a)
No & Type of Engines:	4 electric motors
Year of Manufacture:	Not known (Serial no: not known)
Date & Time (UTC):	29 June 2020 at 1730 hrs
Location:	Eton Wick, Windsor
Type of Flight:	Private
Persons on Board:	Crew - N/A Passengers - N/A
Injuries:	Crew - N/A Passengers - N/A
Nature of Damage:	UA destroyed, damage to third party vehicle
Commander's Licence:	Other
Commander's Age:	Not disclosed
Commander's Flying Experience:	Hours not provided Last 90 days - not known Last 28 days - not known
Information Source:	Limited information submitted by the pilot and enquiries made by the AAIB

Synopsis

The UA was being flown near Eton Wick, Windsor, in a semi-rural area when, without warning, it descended out of control and hit a car parked on a private residential driveway. The car bodywork was damaged and the UA disintegrated on impact. The cause of the accident is not known.

History of the flight

The UA was being flown from an open field in what the pilot described as "wind, but not above 18 to 19 mph". The pilot was monitoring and watching the UA going through its landing procedure. He then observed what looked like a propeller coming apart and the aircraft fell out of control. It hit a car parked on a private residential driveway damaging the cars bodywork. The UA disintegrated on impact. After discussion with the owner of the car and an exchange of details, the remains of the UAS, including its damaged battery, were removed from the site by its owner.

Earlier on the same day this UA had been seen by another UAS pilot who was conducting authorised flying at Windsor racecourse. The pilot was concerned about the risk of another UA operating in the vicinity and near members of the public whilst racing was underway. He approached the pilot, and owner, of the accident UA and asked them to move away, which they did. They resumed flying at a different location, and it was near this new location the accident occurred.

The pilot considered what might have happened to the propeller and concluded that it had been hit by something.

AAIB comment

AAIB reports, such as this, usually include more details regarding the UA and its pilot. In this case this information was not made available to the AAIB. The UA was beyond repair and the owner stated that they had disposed of it immediately after the accident. The UA controller was made available to the AAIB but contained no useful information.

Without an examination of the UA wreckage or the data it contained, it has not been possible to determine the exact cause of this accident.

Safety issue

The batteries of a UA contain large quantities of stored energy and should be handled with great care when damaged. Special precautions should be taken when handling, transporting or disposing of them. Damaged batteries can go into a thermal runaway condition and release their energy rapidly. This generates large amounts of heat, flames and harmful gases. To mitigate this risk, damaged batteries should therefore only be carried in specially designed commercially available cases or pouches.

AAIB Record-Only Investigations

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

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

The accuracy of the information provided cannot be assured.

Record-only UAS investigations reviewed August - September 2020

23-May-20 **Sky Mantis** Machen, Caerphilly

At the end of a task the UA pitched backwards and halted, then continued momentarily for a couple of seconds, before spiralling to the ground. The manufacturer determined that the cause was software related. A software update has been embodied fleet wide to prevent reoccurrence.

24-May-20 **Parrot Anafi** Bridgend, Mid Glamorgan

During a training flight the pilot engaged the UAS's 'Follow Me' mode to track a colleague in an open grass area. The pilot intended to press the 'Anti-clockwise Orbit' button to avoid a building, but accidentally hit the adjacent 'Clockwise Orbit' button. The pilot realised his error and took manual control, but within seconds the UA collided with a wall.

2-Jun-20 **Prion MK3-008** Sutton Meadows Airfield, Cambridgeshire

On a flight check of the UAS, the operator could not conduct a normal landing due to an inability to sufficiently reduce engine speed to idle. The engine was shut down and the aircraft glided to land in an agricultural field in which it sustained considerable damage. An inlet manifold cylinder head gasket leak was determined as the primary cause of the heightened idle rpm.

8-Jun-20 **DJI Inspire 2** Thorpe Park, Surrey

When about 250 to 300 m from the pilot and at 10 m agl, whilst tracking a motorboat on a lake, the UA experienced a loss of control signal. Despite the UA being pre-programmed to hover in this situation, it maintained its heading, collided with a tree and entered the lake. It was subsequently recovered with damage to the airframe, two propellers and the gimbal.

3-Jul-20 **DJI Mavic 3 Enterprise Dual** Halesowen, West Midlands

The UAS lost control and landed on the ground in a built up area. The rotor blades of the UAS were damaged.

9-Jul-20 **Parrot Anafi Thermal** Stoke-on-Trent, Staffordshire

After pre-flight checks had been completed and the propellers confirmed as secure, the UA subsequently lost control in flight, probably due to the loss of a propeller in flight.

12-Jul-20 **DJI Phantom 4** Boston, Lincolnshire

During a flight to survey a road junction the UAS battery level dropped to zero and the UA fell to the ground. A pre-flight risk assessment by the pilot ensured no one was in the vicinity of the UAS during the flight. The UAS was damaged beyond economical repair.

Record-only UAS investigations reviewed August - September 2020 cont

17-Jul-20 **DJI Inspire 2** Immingham, South Humberside

As the UA was approaching overhead power lines, on an automated flight plan, the pilot observed one of the rotor blades separate from the aircraft and the aircraft dropped to the ground. The UAS operator has since revised its risk assessment and increased the operating height to take account of potential obstacles.

24-Jul-20 **Yuneec Typhoon H520** Waterlooville, Hampshire

At a height of 65 m over a congested area, the UA lost power and fell to the ground, there were no injuries. The UK agent attributed the cause of the power loss to the battery moving in its holder disrupting the electrical connection. An additional clamp has been developed to better secure the battery.

28-Jul-20 **DJI Phantom 4** Drakelow, Derbyshire

The UAS lost GPS and compass signals immediately after takeoff and drifted into an electrical sub-station. The operator was unable to take manual control in time to prevent the UA from striking the base of a high voltage pylon.

3-Aug-20 **Parrot Anafi** Preston, Lancashire

The operator received a lost connection warning on his controller when the UA was at low level just above a copse of trees. He lost sight of the UA and it was subsequently found amongst the trees. It has a Return to Home function which operates on loss of connection but, as it was low over the trees, it is likely the UA hit a tree during an attempted return.

7-Aug-20 **DJI Matrice 210 V2 RTK** South Arne Wellhead Platforms East, North Sea

The UA struck a steel column shortly after takeoff in GPS mode, due to an uncommanded movement. The operator did not take manual control in time to prevent the rotors contacting the column, and the UAS fell approximately 1.5 m to the floor, causing damage to the landing gear and rotors.

10-Aug-20 **DJI M210 RKT** Gannet Platform, North Sea

During a visual inspection of the gas flare structure, the UA became unresponsive and flew into the steel structure. The UAS was recovered but no faults could be found.

21-Aug-20 **DJI Mavic 2 Enterprise Dual** Hulme, Manchester

The UA struck a tree in gusty conditions, and fell 10 ft to the ground suffering internal damage as well as damage to a rotor arm.

Record-only UAS investigations reviewed August - September 2020 cont

27-Aug-20 **DJI Phantom** Margate, Kent
The UA suffered a bird strike to the propellers during flight causing the UA to fall to the ground.

27-Aug-20 **DJI Matrice 600 Pro** Broxbourne, Hertfordshire
The UA suffered a hard landing and came to rest inverted. The propellers remained turning until they were manually powered off.

31-Aug-20 **DJI Phantom 4** Luskentyre Beach, Isle of Harris
The UA was being flown back to the operator into a head wind of approximately 20 mph. To increase progress, the operator selected Speed mode and the UA was seen to 'flip' and fall from the sky. The UA was badly damaged.

6-Sep-20 **Mavic Pro 1** Caversham Lakes, Reading, Berkshire
The UAS lost connection with the controller, and is believed to have landed in a lake.

9-Sep-20 **Wingcopter 178 Heavy lift 0037** Compton, near Newbury, Berkshire
The operator was conducting a manual training flight to build currency hours. While transitioning between fixed wing to hover mode the controller lost control and the UAS struck the ground.

11-Sep-20 **DJI Matrice 210** Ipswich, Suffolk
The UA collided with tree branches on takeoff, damaging the propellers and causing the UAS to fall and strike a car roof. No contributing factors were reported.

13-Sep-20 **DJI Matrice 210 V2** Bath Racecourse
At then end of an otherwise normal flight the UA fell onto grass from 21 ft causing substantial damage. No complicating factors were reported.

18-Sep-20 **Mavic Pro** Huntingdon, Cambridgeshire
The UAS reported compass and Inertial Measurement Unit errors, and drifted off course. It struck a tree and fell to the ground. It could not be located.

22-Sep-20 **DJI Phantom 3 Pro** Bradwell Power Station, Essex
The UAS lost datalink whilst carrying out a structural inspection, probably due to interference from the structure. The UA came into contact with the structure damaging the UA.

Record-only UAS investigations reviewed August - September 2020 cont

29-Sep-20 **DJI Phantom 4 Pro** Bristol Docks

The UA flew into a crane after the operator inadvertently pressed the Return to Home Button.

Miscellaneous

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

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

TEN MOST RECENTLY PUBLISHED FORMAL REPORTS ISSUED BY THE AIR ACCIDENTS INVESTIGATION BRANCH

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

Published September 2014.

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

Published July 2015.

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

Published August 2015.

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

Published October 2015.

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

Published March 2016.

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

Published September 2016.

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

Published March 2017.

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

Published March 2018.

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

Published November 2018.

1/2020 Piper PA-46-310P Malibu, N264DB
22 nm north-north-west of Guernsey
on 21 January 2019.

Published March 2020.

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GLOSSARY OF ABBREVIATIONS

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

Air Accidents Investigation Branch