Air Accident Investigation Unit Ireland

SYNOPTIC REPORT

SERIOUS INCIDENT
Cessna 182L, EI-CDP
Clonbullogue Airfield, Co. Offaly, Ireland

6 October 2018

An Roinn Iompair
Department of Transport

Foreword

This safety investigation is exclusively of a technical nature and the Final Report reflects the determination of the AAIU regarding the circumstances of this occurrence and its probable causes.

In accordance with the provisions of Annex 13[1] to the Convention on International Civil Aviation, Regulation (EU) No 996/2010[2] and Statutory Instrument No. 460 of 2009[3], safety investigations are in no case concerned with apportioning blame or liability. They are independent of, separate from and without prejudice to any judicial or administrative proceedings to apportion blame or liability. The sole objective of this safety investigation and Final Report is the prevention of accidents and incidents.

Accordingly, it is inappropriate that AAIU Reports should be used to assign fault or blame or determine liability, since neither the safety investigation nor the reporting process has been undertaken for that purpose.

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[1] **Annex 13**: International Civil Aviation Organization (ICAO), Annex 13, Aircraft Accident and Incident Investigation.
[2] **Regulation (EU) No 996/2010** of the European Parliament and of the Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation.
[3] **Statutory Instrument (SI) No. 460 of 2009**: Air Navigation (Notification and Investigation of Accidents, Serious Incidents and Incidents) Regulations 2009.

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In accordance with Annex 13 to the Convention on International Civil Aviation, Regulation (EU) No 996/2010 and the provisions of SI No. 460 of 2009, the Chief Inspector of Air Accidents, on 8 October 2018, appointed Clive Byrne as the Investigator-in-Charge to carry out an Investigation into this Serious Incident and prepare a Report.

Aircraft Type and Registration:	Cessna 182L, EI-CDP	
No. and Type of Engines:	1 x Continental O-470-R	
Aircraft Serial Number:	182-58955	
Year of Manufacture:	1968	
Date and Time (UTC)[4]:	6 October 2018 @ 17:09 hrs	
Location:	Clonbullogue Airfield (EICL), Co. Offaly, Ireland	
Type of Operation:	Specialised Operations - Parachuting	
Persons on Board:	Crew – 1	Other – 4
Injuries:	Crew – Nil	Injuries – Nil
Nature of Damage:	Substantial Engine Damage	
Commander's Licence:	Commercial Pilot Licence (CPL) Aeroplane (A) issued by the Portuguese Aviation Authority (ANAC)	
Commander's Age:	39 years	
Commander's Flying Experience:	890 hours, of which 200 were on type	
Notification Source:	Aircraft Operator at EICL	
Information Source:	AAIU Report Form submitted by the Pilot AAIU Field Investigation	

[4] **UTC**: Co-ordinated Universal Time. All times in this report are quoted in UTC unless otherwise stated; local time was UTC +1 hour on the date of the occurrence.

SYNOPSIS

During a parachute operations flight conducted from Clonbullogue Airfield (EICL), Co. Offaly, the aircraft, with one Pilot and four Skydivers on board, experienced uncharacteristic engine vibrations and a reduction in power. It was unable to continue its climb and the Pilot elected to return to the airfield. During the return, the engine power reduced further and a short time later the engine failed completely. The Pilot conducted an emergency landing on Runway 09. During the landing, the aircraft skidded sideways along the grass runway and came to a stop on a tarmac area beyond the end of the runway. The Pilot and four Skydivers were uninjured and evacuated the aircraft. The aircraft engine was subsequently found to have sustained substantial damage. There was no fire.

NOTIFICATION AND RESPONSE

The AAIU was notified of the occurrence by the aircraft Operator at EICL.

1. FACTUAL INFORMATION

1.1 History of the Flight

The aircraft departed EICL on its seventeenth parachute operations flight of the day. The Pilot reported that the weather conditions were good and that there was a northerly wind. The take-off from Runway (RWY) 27 was described as uneventful. At approximately 3,500 feet (ft) in the climb, the Pilot noticed uncharacteristic engine vibrations and a reduction in power which prevented the aircraft from climbing. He broadcast on the airfield frequency, reporting an '*engine failure*' and that his intention was to return to the airfield.

The Pilot initially commenced an approach onto RWY 27; however, the setting sun, which was low in the sky, adversely affected his vision for the intended approach. The Pilot stated that he then opted to '*try to go all the way to RWY 09*' (the reciprocal runway) as he still had '*some power*'. Passing to the north of the airfield, the aircraft continued in a westerly direction at approximately 450 ft AGL (above ground level). Having just passed overhead of some farm buildings, the engine failed completely, and all power was lost. The aircraft started to lose altitude and the Pilot, aware of trees on the approach to RWY 09, opted to execute a 180-degree turn to the left with the intent of lining up with RWY 09. During the turn, the stall warning horn activated intermittently. The aircraft crossed the centreline for RWY 09 and passed over a field to the right of RWY 09 before finally aligning with the centreline approximately 360 metres from the end of the runway.

The Pilot informed the Investigation he was aware that due to the rate of descent and speed of the aircraft, it would overshoot the runway. Therefore, he opted to put the aircraft down onto RWY 09 as soon as possible. Due to the speed of the aircraft and the prospect of colliding with the boundary hedge and fence beyond the end of the runway, the Pilot said he applied full left rudder and aileron to turn the aircraft and it skidded sideways along the grass runway (**Figure No. 1**).

Figure No. 1: Sideways skid of aircraft coming to the end of grass surface

Video evidence and ground scarring show that as the aircraft skidded sideways, the left wing pitched down and the right wheel lifted off the ground. The tail struck the ground as the nose wheel lifted. The aircraft, still moving in a sideways motion, departed the grass surface onto a tarmac area beyond the end of the runway. The aircraft came to a stop on the tarmac on a heading of 020 degrees magnetic, approximately 7 metres (m) from the airfield's eastern boundary hedge and fence (**Figure No. 2**). The Pilot and Skydivers evacuated the aircraft. No injuries were reported to the Investigation. There was no fire.

Figure No. 2: Resting position of EI-CDP

1.2 Airfield Information

Clonbullogue Airfield (EICL) is situated in Co. Offaly at an elevation of 240 ft AMSL[5]. The airfield has one grass runway which is designated RWY 09/27. The runway is 770 m in length and 18 m in width (**Figure No. 3**). Other features include an aircraft hangar, fuel farm and clubhouse.

[5] **AMSL**: Above Mean Sea Level

Figure No. 3: Aerial view of EICL (*Google Earth*)

1.3 Injuries to Persons

No injuries were reported to the Investigation.

1.4 Damage to Aircraft

1.4.1 Airframe Damage

The hub of the right main landing gear wheel was broken along its outer circumference and is indicated by the yellow circle in **Photo No. 1** adjacent to a step modification fitted to the landing gear strut. The tie-down point under the tail of the aircraft was distorted to the left (yellow circle in **Photo No. 2**).

Photo No. 1: Right main landing gear wheel

Photo No. 2: Tie-down point

1.4.2 Engine Damage

The aircraft engine exhibited significant damage. On initial visual inspection a hole was evident in the engine crankcase adjacent to the No. 3 cylinder (**Photo No. 3**). The engine was subsequently removed from the aircraft under AAIU supervision and sent to an approved engine maintenance facility for further investigation, also under AAIU supervision (**Section 1.12**).

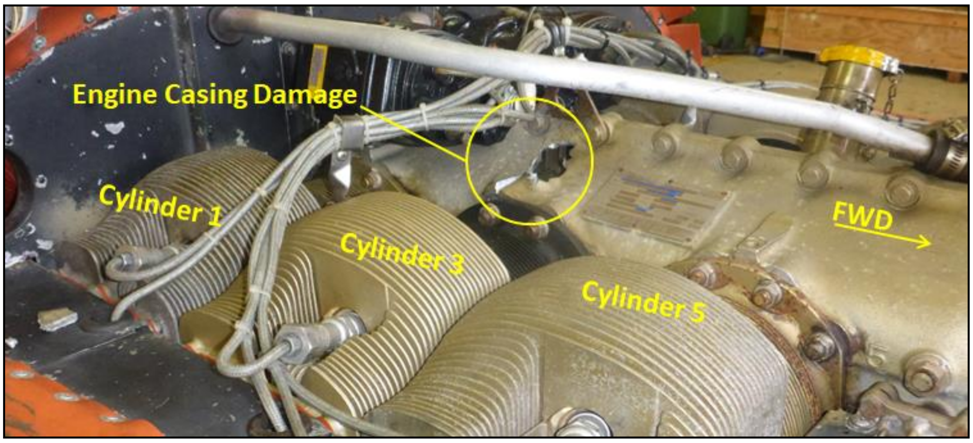

Photo No. 3: Engine damage

1.5 Other Damage

There was localised scarring to the grass surface in several areas along the final 125 m of RWY 09. The closed-circuit television (CCTV) footage indicates that this scarring was consistent with the sideways motion of the aircraft wheels and the tail strike as it skidded along the runway during the emergency landing. In addition, there was minor damage to the tarmac surface beyond the end of RWY 09.

1.6 Personnel Information

The Pilot held a European Union CPL (A) issued by the Portuguese National Civil Aviation Authority (ANAC[6]) with a Single Engine Piston (SEP) rating with an expiry date of 31 December 2018 and held a Class 1 Medical Certificate that was valid until 31 October 2019. **Table No. 1** sets out the Pilot's flying experience.

Total all types:	890 hours
Total on type:	200 hours
Last 90 days:	150 hours
Last 28 days:	58 hours
Last 24 hours:	5 Hours 35 minutes

Table No. 1: Pilot's flying experience

[6] **ANAC:** Autoridade Nacional de Aviação Civil. Portuguese Civil Aviation Authority.

1.7 Interviews

1.7.1 Pilot Interview

The Pilot said that after landing, from a previous parachute drop, he picked up the next contingent of skydivers from the loading area as normal. The Pilot stated that the occurrence flight was his seventeenth of eighteen flights scheduled for the aircraft that day.

With the wind from the north, the flights had been taking off from RWY 27 and landing on RWY 09 throughout the day. With the skydivers on board, he took off from RWY 27. The intended drop altitude was 10,000 ft. At approximately 3,500 ft the Pilot '*felt a loss of power'* and that the aircraft was losing altitude. The Pilot, concerned with the loss of engine power, decided that he would return to the airfield. He broadcast on the airfield frequency that the aircraft had an '… *engine failure and that* [he] *was coming back to the field*'. The Pilot informed the Investigation that he briefed the skydivers on the situation and that he was returning to the airfield.

The Pilot positioned the aircraft for an approach onto RWY 27. However, the evening sun was low in the sky, and from previous experience at the airfield, he knew that '… *at the end of the day you have no visibility on* [runway] *27*'. The Pilot decided that as the engine was still producing some power, he was going to '*try to go all the way to Runway 09'*.

As the aircraft was on a left downwind leg for RWY 09 the Pilot selected full flaps to prepare for the landing. As the flaps began to move, the Pilot heard '*… the clank* [engine shutdown] *on the engine*'. The Pilot said he felt the aircraft sinking and he considered that at his current height he would not clear the trees on the approach to RWY 09, so he decided to cut short his downwind leg and make an immediate 180 degree turn to the left in an attempt to line up with RWY 09. During the left turn, the aircraft crossed the centreline for RWY 09 and passed over a field to the right of RWY 09 before finally aligning with the centreline.

The Pilot said that with the aircraft travelling at an airspeed of approximately 60 knots (kt), he put the aircraft *'down hard'* on the runway. In an effort to reduce the aircraft's speed, avoid a runway excursion and possible impact with the fence beyond the end of RWY 09, he applied full left rudder and full left aileron which turned the aircraft *'completely sideways'* as it continued to travel along the runway. **Figure No. 4** provides a schematic overview based on the Pilot's account and on video evidence examined by the Investigation as to the estimated flight path taken by the aircraft.

Figure No. 4: Estimated emergency landing route (*Google Earth*)

Points A and B indicate the first and second points of contact of the aircraft with the runway. Point A is 125 m and Point B is 102.5 m respectively from the tarmac at the end of the RWY 09.

The Pilot noted that in addition to the seventeen flights on the day of the occurrence, he had also flown the aircraft the previous day and stated that the aircraft and engine had been operating normally.

1.7.2 Skydiver Interviews

The skydivers who were interviewed provided accounts of the occurrence. All were aware that an issue with the engine had occurred, and that the aircraft was returning to the airfield. One of the more experienced Skydivers noted that the engine *'was at a different pitch than you would expect if climbing'* and asked the Pilot if there was an issue. The Pilot indicated to him that the aircraft was returning to the airfield. The Skydiver noted, in the interview, that an issue causing an aircraft to return to the airfield may occur from time to time and he initially considered that this was the case on this occasion. The possibility of the skydivers bailing out of the aircraft prior to the landing was not discussed between the Pilot and the skydivers during the flight.

During the interview it was noted that, in a normal aborted flight with skydivers on-board for the landing, the aircraft's rate of descent is reduced to account for the Automatic Activation Devices[7] (AAD) fitted to the parachutes. The Skydiver said that at this point he realised that the engine *'did not sound right'* and his '*Dytter*'[8], which was set at 1,500 ft, activated a warning tone in his helmet alerting him to the aircrafts reducing altitude. With the engine *'sounding worse'* the aircraft was now descending and was north of RWY 27 and approximately parallel to it. He said that at an altitude estimated at between '*700 - 900 ft*' the engine stopped and he '*could feel the aircraft shudder'*.

The Skydiver said he thought that the aircraft would land in another field rather than the airfield and that the Pilot was '*working very hard to manage the aircraft'*. The aircraft then made what was described as '*an aggressive turn left towards the runway* [RWY 09]' and the Pilot had to correct somewhat to line the aircraft up with the runway. All of the skydivers were instructed to adopt the '*brace*' position and grab their respective restraint straps. The Skydiver said that he, as well as another skydiver, then shouted *'BRACE, BRACE, BRACE'* just before touchdown. All skydivers interviewed confirmed hearing the instruction and that prior to the occurrence flight they had been briefed on the applicable procedures for a bail out or an emergency landing. All skydivers interviewed also noted that they sustained no injuries as a result of the occurrence.

[7] **Automatic Activation Device:** A device fitted to a skydiver's parachute which monitors the rate of descent and altitude and starts a sequence for the reserve parachute deployment if the skydiver passes below a set altitude at a high rate of descent without the main chute having been deployed.
[8] **Dytter:** Proprietary eponym used to describe an altimeter device used by skydivers to provide audible tones at pre-set altitudes.

1.8 Recordings

1.8.1 General

CCTV footage of the aircraft's movements in the vicinity of the airfield was obtained from the airfield Operator and examined by the Investigation. In addition, on-board video recordings made during the flight and the landing were obtained and examined.

1.9 Meteorological Information

Met Éireann, the Irish meteorological service, was asked to provide an aftercast of the weather conditions prevailing in the Clonbullogue area at the time of the occurrence. The Meteorological aftercast stated that a ridge of high pressure moved in from the west and the air became more stable as the day progressed. Details from the report received are summarised in **Table No. 2**.

Surface Wind: **Wind at 2,000 ft:** **Between Surface and 300 ft:**	North-west at 5 kt. North-west at 15 kt. The surface flow was north-westerly and well established. Given the slack pressure gradient and light breezes, only slight variations in wind velocity - no more than a couple of knots, and wind direction - no more than 10-20 degrees were likely between the surface and 300 ft.
Visibility:	30+ km.
Weather:	Sunshine with isolated fair weather cloud and light rain showers.
Cloud:	No significant cloud – isolated FEW (1-2/8th oktas[9]) with cloud bases between 2,500 and 5,000 ft.
Surface Temperature/Dew Point:	10/2 degrees Celsius.
Mean Sea Level (MSL) Pressure:	1020 hectopascals (hPa).

Table No. 2: Weather conditions in the Clonbullogue area at the time of the occurrence

1.10 Aircraft Information

1.10.1 General

The Cessna 182L is an all-metal, high wing aircraft with a fixed landing gear. The occurrence aircraft, EI-CDP, was manufactured in 1968 and has a maximum gross weight of 2,800 lb (1,270 kg). The aircraft was fitted with a Hartzell, two-blade, aluminium alloy, variable pitch propeller.

[9] **Oktas:** Unit of cloud amount, expressed as number of eighths of the sky dome that is covered by clouds.

The subject aircraft was fitted with a restraint arrangement for the Pilot consisting of a lap belt and a diagonal shoulder strap. The aircraft was modified for parachute operations. The skydivers restraint arrangement consisted of a cushioned mat, and aircraft mounted restraint straps (**Section 1.10.4**). The right main landing gear strut was fitted with a step which assists in skydivers exiting the aircraft prior to their jump.

The aircraft was first registered in Ireland on 20 May 1991 and registered to the Operator on 14 January 1997. The aircraft's Certificate of Airworthiness (C of A) was issued by the Irish Aviation Authority (IAA) on 26 June 2011 and an Airworthiness Review Certificate (ARC), first extension, was issued by an IAA-approved continuing airworthiness organisation on 16 February 2018 and was valid until 16 February 2019.

1.10.2 Aircraft Performance

The Owner's Manual (OM) for the Cessna 182L (1968) recommends an approach speed of 69 MPH (60 kt) with flaps extended to 40 degrees (Full Flaps). The OM indicates that the stall speed for the aircraft with '*Power Off*' varies with the angle of bank and flap configuration. A range of combinations are shown in **Table No. 3**. The manual states that an aural warning is provided by a stall warning horn which sounds '*… between 5 and 10 MPH above the stall in all configurations*'. The table indicates that between 30 and 60 degrees angle of bank the stall speed is 59 to 78 MPH (51 to 68 kt).

STALL SPEED, POWER OFF			
Gross Weight 2800 LBS.	ANGLE OF BANK		
CONFIGURATION	0°	30°	60°
FLAPS UP	64	69	91
FLAPS 20°	57	61	81
FLAPS 40°	55	59	78
SPEEDS ARE MPH, CAS			

Table No. 3: Cessna 182L Stall Speed, Power Off combinations

1.10.3 Engine

EI-CDP was fitted with a Teledyne Continental Motors (TCM) O-470-R 230 horsepower, six-cylinder, horizontally opposed engine (Serial number 834202-R). The cylinders on this type of engine are arranged as per **Figure No. 5**.

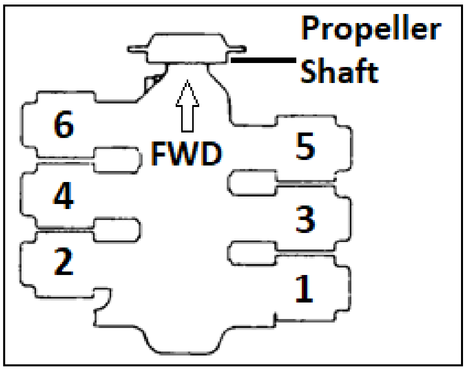

Figure No. 5: TCM 400 series engine numbering system (viewed from above)

The engine crankshaft is arranged and identified as illustrated in **Figure No. 6**. On this engine type all crankshaft components are numbered from aft to forward. The number four main journal (MJ #4) is most forward, closest to the propeller flange and is supported by two separate main bearings, numbers four and five. All crankshaft bearings are of the 'plain' type. The Engine Manufacturer refers to the crankshaft webs as '*cheeks*', and the big-end journals as '*rod journals*' (RJ). The engine crankshaft rotates clockwise as viewed from the cockpit of the subject aircraft.

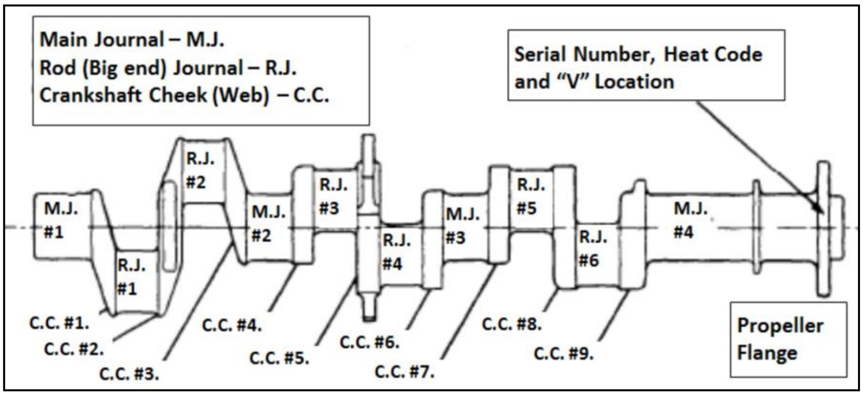

Figure No. 6: Crankshaft component identification (Teledyne Continental CSB96-8)

1.10.4 Occupant Restraint

The four skydivers were sitting on a cushioned mat, and each was attached to the aircraft using restraint straps as shown in **Photo No. 4**. The Pilot was restrained using the lap strap.

Photo No. 4: Skydiver restraint system

1.11 Aircraft Maintenance History

1.11.1 General

The aircraft was maintained by an IAA-approved Part 145 maintenance organisation. The scheduled inspections that applied to the aircraft included recurring 50-hour, 100-hour, and annual inspections in addition to calendar and other inspections in accordance with the Aircraft and Engine Manufacturer's requirements. Supplementary worksheets were used to itemise where maintenance outside of the scheduled maintenance was required and performed.

1.11.2 Engine Maintenance History

At the time of the occurrence, the aircraft had recorded a total of 5,732 hours flying time. The engine was fitted to the aircraft on 24 August 2007 and had recorded a total of 1,238 operating hours since its last overhaul.

On 14 November 2017, a routine 50-hour inspection was commenced. As part of the 50-hour inspection, low cylinder compression was noted on the No. 3 and No. 4 cylinders. Following troubleshooting, both the No. 3 and No. 4 cylinders were removed and sent to an approved engine repair facility for repair. On return of the repaired cylinders, both were refitted to the engine, re-tested for correct compression and the engine was returned to service. The aircraft was released to service on 15 February 2018. This was 219 flying hours before the occurrence.

Following the cylinder repair work noted above, an annual inspection and two 50-hour and two 100-hour inspections were completed on the aircraft with no significant engine maintenance required. Maintenance records show that on 18 September 2018, 25 flight hours prior to the occurrence, the engine oil and oil filter were replaced as part of a 100-hour engine inspection and no anomalies were noted.

1.12 Engine Disassembly and Inspection

1.12.1 General

Under the supervision of the AAIU, the engine was removed from the aircraft. Following removal, the engine was sent to an independent, approved engine overhaul facility for disassembly and inspection. The engine was held in a secure quarantine location at the facility until disassembly commenced under the supervision of the AAIU.

On initial inspection at the engine overhaul facility, it was observed that the engine was partially seized and would not fully rotate. The crankcase situated on the upper right-hand side of the engine exhibited significant damage and was punctured from the inside out. The exact nature of the internal failure was not evident. It was notable at this point that the external paint finish and external condition of Cylinders No. 3 and No. 4 were different to that of the remaining four cylinders. **Photo No. 5** shows Cylinder No. 3 adjacent to the damaged crankcase.

Photo No. 5: L to R – Cylinders No. 1, No. 3 and No. 5

Cylinders No. 1, 2, 5 and 6 and their respective pistons were removed, and no anomalies were noted on either the cylinders, pistons or their attaching hardware and components. Internal inspection of the engine at this point indicated that a failure of the crankshaft had occurred in the general area of the No. 3 and No. 4 cylinders.

With all cylinders removed it was apparent that the crankshaft had broken into three distinct pieces and had caused a significant amount of secondary damage to the crankcase, connecting rods and cylinders. A large, detached section of crankshaft could be observed wedged just below the fractured crankcase (**Photo No. 6**).

Photo No. 6: Detached section of crankshaft

With the cylinders and pistons removed, a large, detached piece of the crankshaft and associated damage was evident in the No. 3 cylinder area as shown circled in **Photo No. 7** and **Photo No. 8**.

Photo No. 7 (left) and **Photo No. 8** (right)**:** Detached section of crankshaft

On removal of the oil sump, a significant amount of metallic debris was found. This included steel (suspected to be crankshaft sections), aluminium alloy casing fragments and remnants of plain bearing shell material. Apart from the metal deposits found, the oil sump was inspected and found to be in a satisfactory condition and residual engine oil was observed to be present. The engine oil cooler was also removed and inspected, and a large quantity of metal particles and debris was located internally within the oil cooler. The oil filter was inspected, and it was also found to be contaminated with steel and aluminium debris.

The crankcase halves were separated, and it was observed that the damage to the crankshaft was largely confined to the No. 2 main journal and bearing location. The crankshaft was found in three distinct pieces, with each piece displaying a number of fracture surfaces as shown in **Photo No. 9**. In addition, some smaller fragments of the crankshaft had broken away and had been damaged beyond visual recognition.

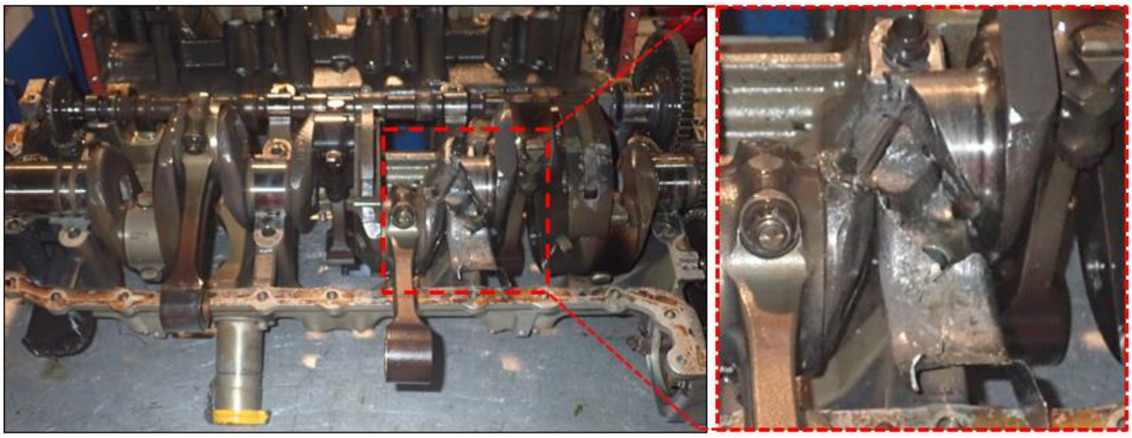

Photo No. 9: Damaged crankshaft sitting in the L/H crankcase

The crankshaft was removed from its case and laid out as shown in **Photo No. 10**. The damage to the crankshaft was found to be centred on a fracture in the No. 2 main journal area (refer to **Figure No. 6**).

Photo No. 10: Damaged crankshaft as removed from the crankcase

With the crankshaft removed from the engine casing, the full extent of the damage to the crankcase and the internals of the engine could be observed. The No. 2 main bearing shell as fitted on the right-hand crankcase half, suffered significant distress and distortion as shown in **Photo No. 11**.

Photo No. 11: No. 2 main bearing shell damage (R/H crankcase)

The No. 2 bearing shell on the L/H crankcase also suffered significant distress and distortion as shown circled in red in **Photo No. 12**. Remnants of the aluminium bearing shell were retrieved from the engine sump and from within the oil cooler.

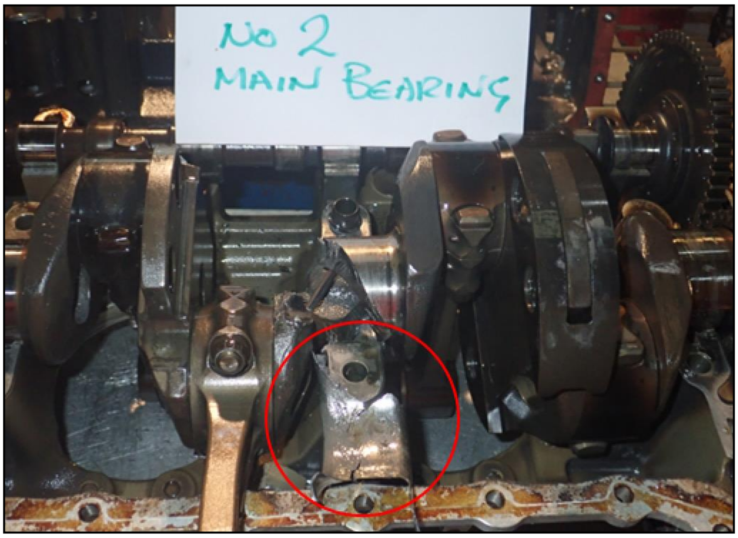

Photo No. 12: No. 2 main bearing shell damage (L/H crankcase)

1.12.2 Crankcase Inspection

A detailed inspection of the crankcase halves indicated that the sealant specified by the Engine Manufacturer had been applied to the required areas.

1.12.3 Crankcase Fretting

Prior to the engine disassembly and for completeness, a torque check using a single calibrated torque wrench, in daily use at the approved engine overhaul facility, was completed on the crankcase through-bolt nuts on the right and left crankcase. This involved initially setting the torque wrench to the minimum allowable torque as specified in the applicable engine overhaul manual. The result of the torque check indicated that all of the through-bolt nuts, apart from one, were found to be within the allowable torque range as specified in the manual.

The nut which failed the torque check required a half turn to bring it to the minimum torque range as specified in the engine manual. The nut was on the right crankcase which secures a through-bolt passing from the No. 3 cylinder flange, through the right and left No. 2 main bearing crankcase saddle and onwards to the No. 2 cylinder flange where it is secured by a similar nut. In discussions with the Engine Manufacturer, the Investigation was informed that '*once the crankcase has been breached*, *through-bolt torques are not accurate*'. The Engine Manufacturer advised the Investigation to examine the case halves for evidence of fretting and also for main bearing tang slot wear.

The workshop report detailed evidence of normal wear in most locations on the crankcase halves. Evidence of fretting and tang slot wear of the No. 1 bearing crankcase saddle from the L/H crankcase half is shown in **Photo No. 13** (blue arrow)**.** Mild fretting of the No. 2 main bearing crankcase saddle from the L/H crankcase half in combination with heavy wear to the bearing bore material can be observed in **Photo No. 14**. Fretting to the No. 1 and No. 2 camshaft bearing saddle areas is indicated by the blue arrow in **Photo No. 15** and **Photo No. 16.**

The workshop report noted that:

> *'… the fretting[10] and tang mark wear observed in the number 1 + 2 main crankshaft bearing saddle locations, and number 1 + 2 camshaft bearing and saddle locations, is a lot more severe than you would expect to find in an engine that has reached TBO[11]'.*
>
> […]
>
> *'The fretting observed in these areas, has been manifesting for a period of time due to the movement of the crankcase halves as a result of an underlying issue. The root cause could possibly be attributed to loss of torque to crankcase thru studs'.*

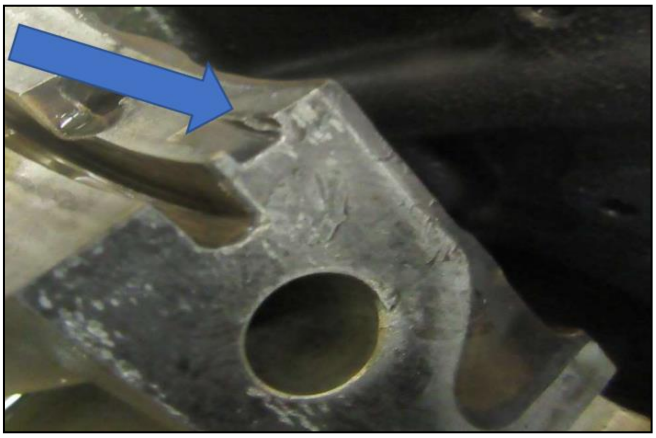

Photo No. 13: Fretting and tang slot wear to the No. 1 main bearing crankcase saddle

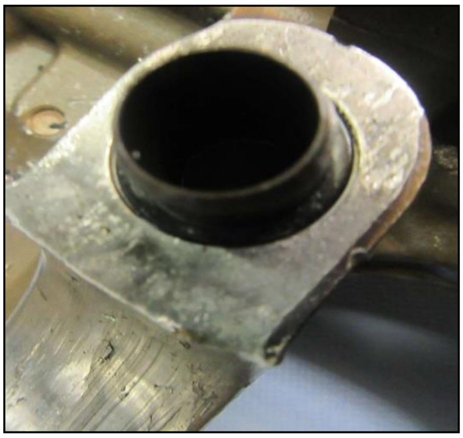

Photo No. 14: Fretting of the No. 2 main bearing crankcase saddle and heavy wear to the bearing bore material

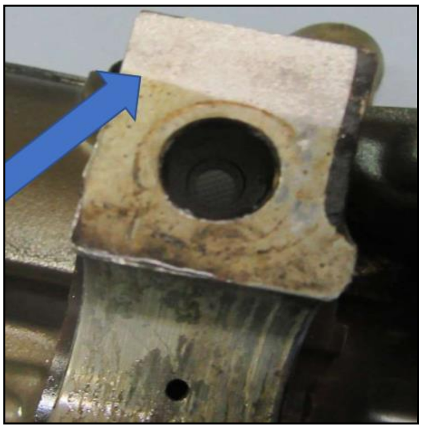

Photo No. 15: Fretting of the No. 1 camshaft bearing saddle

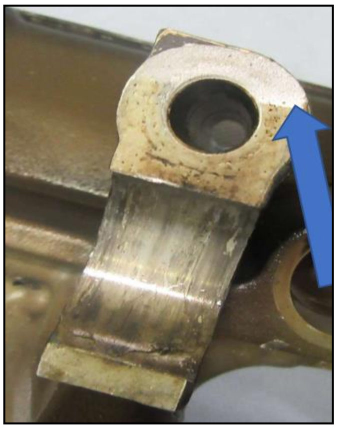

Photo No. 16: Fretting to the No. 2 camshaft bearing saddle

[10] **Fretting:** A wear process that occurs at the contact area between two materials under load and subject to minute relative motion due to vibration or some other force.
[11] **TBO:** Time Between [Engine] Overhaul.

1.12.4 Engine Manufacturer

Details of the damage found to the engine were sent to the Engine Manufacturer for comment. In response, the Engine Manufacturer stated that '*it appears that the bearing shifted. … This is sometimes caused by inadequate torque on the though bolts. The inadequate torque does not apply the proper pinch on the bearing to hold the bearing in place, allowing the bearing to migrate out of the bearing support contacting the crankshaft'*.

1.13 Metallurgical Analysis of Removed Crankshaft

1.13.1 General

The three main crankshaft sections (**Photo No. 17**) were sent to a specialist laboratory for detailed metallurgical analysis to ascertain the cause and mode of failure. The analysis performed included macroscopic examination, magnetic particle testing, energy dispersive x-ray spectroscopy, microhardness testing and detailed examination using a Scanning Electron Microscope (SEM). A detailed report on the analysis and findings was provided to the Investigation. No anomalies were noted in the crankshaft's base material.

Photo No. 17: General view of crankshaft

The report identified that the crankshaft had fractured through MJ #2 (**Photo No. 18**). The fracture planes were complex and had resulted in separation of the journal into three pieces. The outer diameter of MJ #2 showed evidence of scuffing wear and material transferred from the plain bearing. The remainder of the journals showed some oil discolouration but no significant signs of distress.

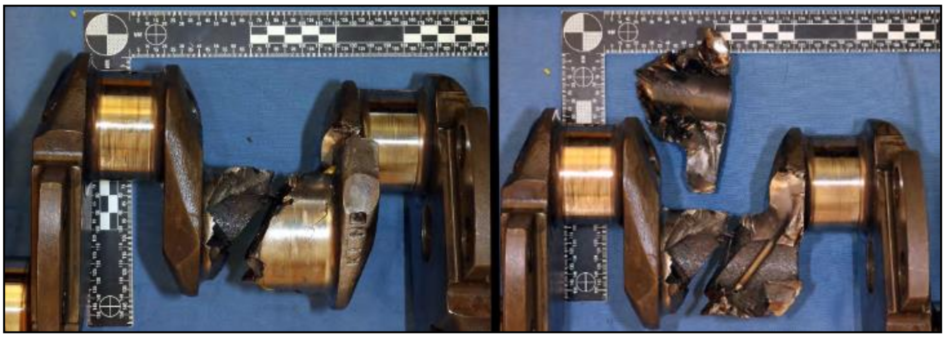

Photo No. 18: General views of failed crankshaft

Examination of radial and conchoidal[12] markings on the fracture surfaces indicated that the failure had occurred by the coalescence of three separate major fatigue cracks, each of which had initiated on the outer diameter of MJ #2. These cracks for ease of reference are arbitrarily identified as Crack #1, #2 and #3 (**Figure No. 7**). There was no evidence of cracking on the outer diameters of any of the journals, other than on MJ #2.

Figure No. 7: Views of the aft portion of MJ #2

1.13.2 Metallurgical Analysis Conclusions

The metallurgical analysis report concluded that:

> '*Metal-to-metal contact between MJ #2 and its plain bearing had caused frictional overheating. This caused the formation of untempered martensite[13] at the surface of the journal and associated heat-induced cracking. With continued engine running, three separate major fatigue crack fronts initiated from the heat-induced cracking and propagated until they coalesced, causing separation of the crankshaft. None of the other journals showed significant evidence of wear or distress'.*

Additional information from the metallurgical analysis report is provided in **Appendix A**.

1.14 Engine Cylinder Replacement Procedures

1.14.1 General

It was noted in the engine maintenance work-pack to address the low compression issue, that the No. 3 and No. 4 cylinders were removed and refitted in accordance with Continental Aircraft Engine Overhaul Manual, Publication X30586, Change 6, October 2013. The procedure for removal and reinstallation of cylinders on the engine is outlined in 72-10-14 and 72-60-03 respectively of the overhaul manual. Additional general guidance is provided in the engine Standard Practice Maintenance Manual.

---

[12] **Conchoidal:** A type of fracture in a solid, which results in a smooth rounded surface resembling the shape of a scallop shell.

[13] **Untempered Martensite:** Martensite is a steel alloy that is hard and brittle. Tempered martensite is martensite that has been subjected to a tempering process to make it softer and more ductile when required for certain applications e.g., crankshaft construction. However, in this case the frictional overheating caused the base material to revert to its untempered state thereby increasing the hardness and brittleness of the crankshaft material.

1.14.2 Cylinder Removal and Reinstallation

The removal and reinstallation of cylinders must be completed in accordance with specific instructions as laid down in the applicable engine manual. Each of the engine's six cylinders is secured to the engine crankcase by means of six threaded studs and two threaded through-bolts (**Figure No. 8**), each of which are secured using nuts. The six threaded studs are screwed into the crankcase half and are sometimes referred to as '*deck studs*'. The through-bolts typically pass from a cylinder flange on the right of the crankcase, through the right and opposite left main bearing crankcase saddle and onwards to the cylinder flange on the left crankcase and each end is secured by a nut.

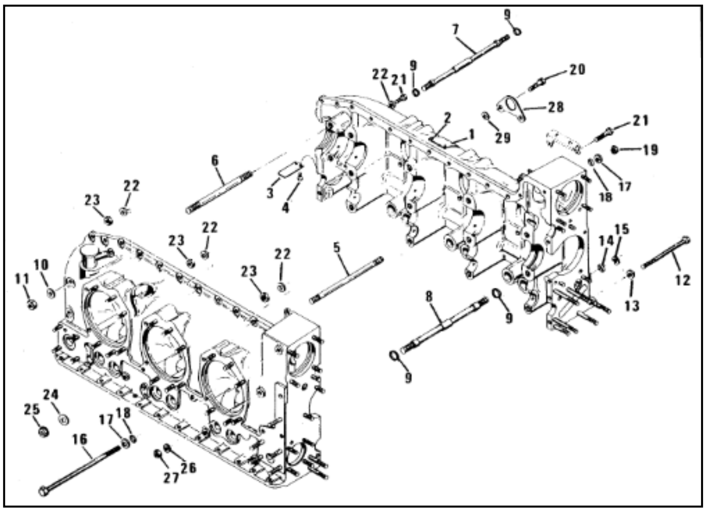

Figure No. 8: Crankcase halves and through-bolt arrangement

(TCM Aircraft Engine IPC Manual)

Special attention must be given to the torquing and sequence of tightening applied to the cylinder flange hold down stud nuts and crankcase through-bolt nuts to ensure an evenly distributed load is applied to the cylinder mating flange and that no distortion is caused. For single cylinder installation, the torquing sequence is as shown in **Figure No. 9**[14]. A warning (**Figure No. 10**) provided in the engine Standard Practice Maintenance Manual regarding the correct cylinder torque procedure for individual cylinder installation, emphasises the consequences for any loss of torque in relation to the through-bolts which '*may result in a loss of main bearing crush, main bearing shift, crankshaft fracture, and engine failure*'.

[14] Continental Aircraft Engine Overhaul Manual: Publication X30586, Change 6, October 2013.

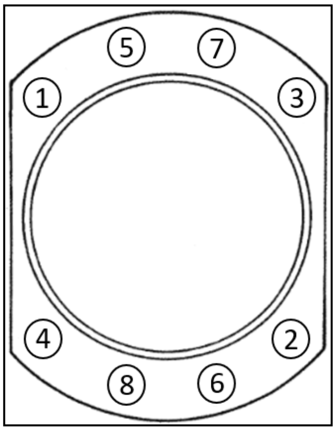

Figure No. 9: Cylinder flange torque sequence for single cylinder installation

> **WARNING**
>
> **Failure to torque through-bolt nuts on both sides of the engine may result in a loss of main bearing crush, main bearing shift, crankshaft fracture, and engine failure.**

Figure No. 10: Warning outlined in engine Standard Practice Maintenance Manual

1.15 Crankshaft Bearings: Installation and Lubrication

The crankshaft main journals rotate in main bearings which are fitted within the crankcase halves. The bearings comprise of two bearing shells or halves manufactured from a metal alloy. The outer diameter of the bearing shell is fractionally larger than that of the diameter of the crankcase bearing housing and therefore the edges of the bearing shell stand slightly proud of the bearing housing during the assembly process. The extent to which the edges stand proud is referred to as the bearing crush or bearing nip. When both crankcase housings are bolted together, the nuts fitted to the through-bolts are tightened on both sides to the specified torque and in a specific sequence as per the maintenance manual. The torquing of these nuts results in the bearing shells being pressed into the crankcase housing thereby providing an interference fit which prevents bearing movement or *'shift'* during operation.

Correct alignment and orientation of the bearing shells within the crankcase housing during assembly is essential and is provided by way of a bearing tang which positions the shell in a dedicated notch in the bearing saddle. Once aligned and fitted correctly, a hole in the bearing shell aligns with an oil supply inlet hole in the crankcase (**Figure No. 11**). When the engine is running, hydrodynamic lubrication, ensures there is a layer (oil-wedge) of lubricant between moving surfaces which prevents the surfaces from making physical contact with each other. The lubricant supplied under the engine's normal operating pressure is constantly being recirculated through the engine oil cooler and oil filter and therefore in addition to preventing wear and friction it also performs an engine cooling function.

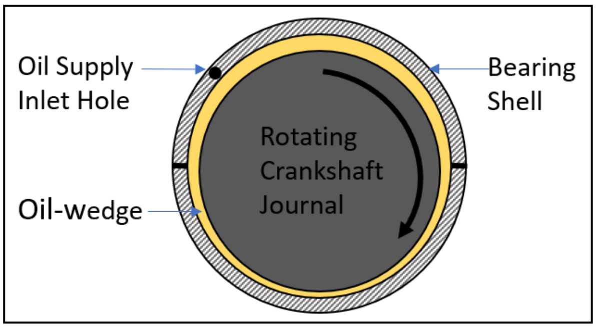

Figure No. 11: Hydrodynamic lubrication

1.15.1 O-470-R Engine Lubrication

The geometry and capacity of the oil sump is designed to lubricate the engine at any permitted nose up or nose down attitude provided that the oil level is maintained at the recommended level shown on the engine oil gauge rod. Lubricating oil is directed under pressure through the passageways from the left oil gallery to the main bearings and camshaft bearings via oil supply holes in the bearings as illustrated in the Lubrication System Diagram[15] in **Figure No. 12**. Except for the damaged area around MJ #2 the engine oil lubrication system was found to be intact and free from obstructions.

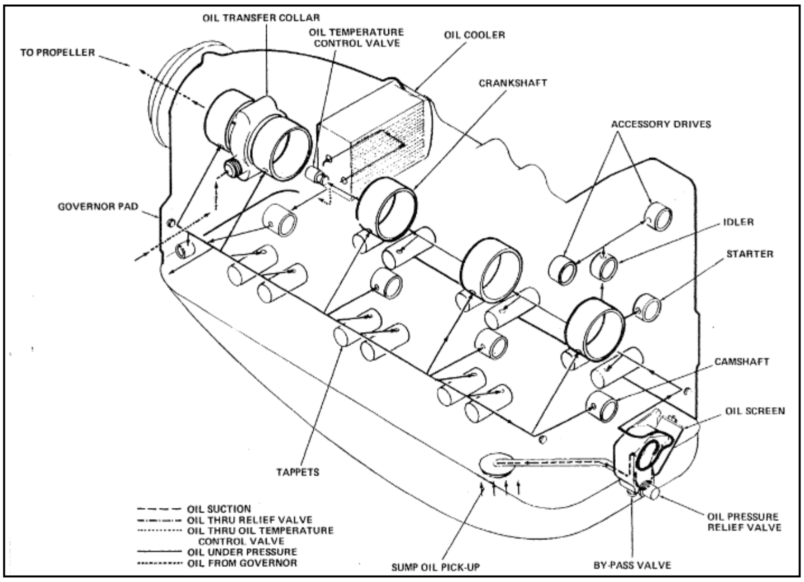

Figure No. 12: O-470-R Lubrication system diagram

1.16 Similar Occurrence

The AAIU published a report[16] in 2015, which related to a forced landing due to a loss of engine power, attributable to a fatigue failure of the crankshaft at the number three main journal. A contributory factor to the event was reported as '*A loss of lubrication at the number three main bearing resulting in metal-to-metal contact between the bearing and the journal*'.

2. ANALYSIS

2.1 Emergency Landing

2.1.1 Approach

The Pilot reported that on passing approximately 3,500 ft, the aircraft began to experience uncharacteristic engine vibrations and a reduction in power and was unable to continue its climb out from the airfield. The Pilot broadcast on the airfield frequency, reporting an '*engine failure*' and that his intention was to return to the airfield.

[15] Continental Aircraft Engine Overhaul Manual: Publication X30586, Change 6, October 2013
[16] **Report Reference:** AAIU - Report No. 2015-017 available at www.aaiu.ie

The Pilot informed the Investigation that the setting sun was low in the sky, and this adversely affected the visibility for the intended approach to RWY 27. He therefore decided against making an approach to this runway and opted to '*try to go all the way to RWY 09*' as he still had '*some power*'. As the aircraft travelled west, at approximately 450 ft AGL, and just after passing overhead of some farm buildings, the Pilot extended the flaps to 40 degrees (Full Flaps) in order to prepare for the landing on RWY 09. Video footage obtained by the Investigation shows that just as the flaps began to extend, the engine failed completely. **Figure No. 13** indicates the approximate track taken by the aircraft after the initial approach to RWY 27 was abandoned and also identifies the approximate position of the aircraft when the engine failed completely.

When the engine failed completely, the Pilot turned the aircraft left towards the airfield and attempted to line up with RWY 09. From footage reviewed, the aircraft banked to the left at an angle of between 30 and 40 degrees. The stall warning horn could be heard activating intermittently as the aircraft was being banked and the Pilot could be observed manipulating the aircraft flight controls as the aircraft was manoeuvred across the runway. The OM states that the stall warning horn sounds '*between 5 and 10 MPH* [4 to 9 kt] *above the stall*' and **Table No. 3** indicates that between 30 and 60 degrees angle of bank the stall speed is 59 to 78 MPH (51 to 68 kt). This is consistent with the Pilot's estimated airspeed of approximately 60 kt.

The aircraft crossed the centreline for RWY 09 and passed over a field to the right of RWY 09 before finally aligning with the runway. At this point, the aircraft had approximately 360 m of grass runway remaining. According to the Pilot, the aircraft was travelling at an airspeed of approximately 60 kt and based on the meteorological aftercast, which indicated a north-westerly wind of 5 kt, there was a potential tailwind component.

Figure No. 13: Approximate emergency landing route (*Google Earth*)

Points A and B on **Figure No. 13** indicate the initial and second points of contact respectively of the aircraft with the runway. Point A is 125 m and Point B is 102.5 m from the tarmac at the end of the runway.

2.1.2 Landing Sequence

The Pilot informed the Investigation that as he was about to touch down, he realised that at the current speed and descent rate, the aircraft would overshoot the runway, so he put it '*down hard*'. The aircraft touched down initially with 125 m of runway remaining.

The aircraft bounced and touched down again 22.5 m later. Conscious of too much speed on landing, and in an attempt to stop the aircraft before the airfield's boundary fence, the Pilot applied full left rudder and aileron to turn the aircraft resulting in a sideways skid down the runway. Such was the motion of the skid, the aircraft transitioned from three wheels in contact with the ground to two wheels in contact with the ground. The aircraft had a momentary tail strike, as evidenced by video footage, damage to the tie down point ring on the bottom of the tail and ground scarring. The fractured portion of the hub of the right main wheel likely separated as a result of the skid either during the initial sideways motion on the grass, or as the aircraft departed the grass surface and entered the tarmac area.

2.2 Engine Failure

2.2.1 General

Disassembly of the engine at an approved engine overhaul facility revealed that the engine had sustained a failure of the crankshaft. Further metallurgical analysis of the crankshaft showed that the crankshaft had failed as a result of '*Metal-to-metal contact between MJ #2 and its plain bearing* [which] *had caused frictional overheating*'.

The aircraft's maintenance records indicate that, approximately 219 flying hours prior to the occurrence, during routine maintenance checks, the engine had undergone troubleshooting for a low cylinder compression issue. As a result, the No. 3 and No. 4 cylinders were removed and sent for repair. Both cylinders were refitted, re-tested for correct compression, and the engine was returned to service.

2.2.2 Metallurgical Analysis of Failed Crankshaft

Metallurgical analysis of the crankshaft, as discussed in **Section 1.13** and **Appendix A**, identified that there were no anomalies noted in the base material. Etched metallographic sections through MJ #1 and MJ #2 identified similar bulk microstructure of tempered martensite which was consistent with hardened and tempered AISI[17] 4340 steel as specified by the Engine Manufacturer. There was also evidence of surface hardening extending inward from the outer diameter on the undamaged MJ #1 which was analysed for comparison with the failed MJ #2. The outer diameter of MJ #2 displayed evidence of a layer of deformed material deposited on the surface. This indicated that there had been metal-to-metal contact between the journal and the bearing. The material deposited on MJ #2 was identified as having elevated levels of aluminium and silicon, which is consistent with engine bearing material. Underneath the deposited material a light etched layer of untempered martensite was revealed. The presence of the untempered martensite indicates that the metal-to-metal contact had generated sufficient heat, in excess of 816°C, to transform the local crankshaft alloy microstructure. The temperature gradients that occur during the formation of untempered martensite will result in high levels of residual stress within the affected area. The magnitude of these stresses is often sufficient to cause surface cracking.

[17] **AISI:** American Iron and Steel Institute.

Analysis of the fracture surfaces on MJ #2 identified that the crankshaft failed due to the propagation and coalescing of three separate major fatigue crack fronts. The fatigue cracks were likely caused by localised overheating arising from friction due to metal-to-metal contact between the bearing and the crankshaft journal. Several other similar cracks, remote from the fracture planes, were also identified on the outer diameter surface of MJ #2.

2.2.3 Lubrication of Main Bearings

Crankshaft main bearings require hydrodynamic lubrication between the bearing and the bearing shell in order to prevent metal-to-metal contact and consequent overheating. Correct alignment between the lubrication port and the oil supply holes in the bearing and correct clamping of the stationary bearing shell are necessary in order to maintain a constant supply of a lubricating and cooling medium. Any restriction to the hydrodynamic lubrication would result in a localised temperature increase at the site of the restriction.

The crankcase oil galleries were found to be clear of obstructions. Maintenance records indicate that 18 days and 25 flight hours before the occurrence, the oil filter and engine oil was replaced during a routine 100-hour engine inspection. No anomalies with the oil system were noted during the 100-hour inspection.

Except for MJ #2, all other crankshaft main journals displayed some normal oil discoloration but no significant signs of thermal distress. They were found to be in good condition and without excessive distortion or wear, confirming the availability of pressurised lubrication oil to the remaining journals.

It is therefore likely, based on the heat-induced cracking of the crankshaft evident from the metallurgical analysis, that lubricating oil was not available to the MJ #2 area. If a bearing shell moves or shifts during engine operation, it can restrict the passage of lubricating oil and the resulting hydrodynamic lubrication necessary to prevent wear, friction and the consequential increase in temperature. Frictional overheating in service may cause deleterious alterations in the surfaces of parts manufactured from steels, which have been hardened and tempered.

Apart from the cracking that ultimately caused the crankshaft to fracture at MJ #2, there were a number of similar longitudinal cracks on the surface of MJ #2 which were likely the result of thermal distress caused by frictional overheating of the outer diameter of MJ #2. In addition, MJ #2 showed evidence of scuffing wear and material transfer from the plain bearing.

2.3 Failure Sequence

2.3.1 Bearing Shift

The security of bearing shells within the crankcase is maintained by the presence of a tang on each bearing shell which fits into a notch in the crankcase half. Bearing crush (also referred to as '*bearing nip*'), by virtue of the application of the correct torque to crankcase through-bolts during assembly, also ensures the correct security of the bearing shells. This is emphasised in the engine's Standard Practice Maintenance Manual, which states that '*failure to torque through-bolts on both sides of the engine may result in a loss of main bearing crush, main bearing shift, crankshaft fracture, and engine failure*'.

2.3.2 Fretting Leading to Bearing Rotation

During disassembly of the engine, all through-bolts were checked for the minimum torque value as described in the manufacturer's manual. This identified that the through-bolt passing from the No. 3 cylinder flange, through the right and left No. 2 main bearing crankcase saddle and onwards to the No. 2 cylinder flange, did not meet the minimum torque value (tightness). The loss of torque at this through-bolt may have been due to the crankshaft failure and the associated damage to the crankcase. However, the significant fretting observed on the mating surfaces of the No. 1 and No. 2 bearing housing/saddles, and the indentations on the bearing saddle faces caused by the tangs of the bearings in the opposite saddles, and the fretting identified on the No. 1 and No. 2 camshaft bearing saddles, indicate that vibration/movement had occurred. This could lead to bearing shift.

2.3.3 Crankshaft Failure Sequence

The metal-to-metal contact between MJ #2 and its plain bearing likely occurred as a result of the oil flow being obstructed due to bearing shift. The frictional heating caused the formation of untempered martensite and associated heat-induced cracking. The propagation and coalescing of three separate major fatigue crack fronts, which initiated from the heat-induced cracking, caused final separation of the crankshaft. Additional surface cracking was also identified elsewhere on the surface of MJ #2.

2.4 Survivability

The Pilot was restrained using the aircraft's lap strap. The four Skydivers were sitting on a cushioned mat, and each were secured with a restraint strap. The aircraft landed with significant energy, and without injury to the Pilot or Skydivers. Notwithstanding that the occupant restraints used likely prevented injury in this case, the Investigation considers it prudent to use all available restraint systems, including pilot shoulder strap(s) where possible, to minimise the risk of serious injury.

2.5 Safety Action from Engine Manufacturer

The Investigation contacted the Engine Manufacturer in relation to the possible loss of torque and possible bearing shift during cylinder replacement. The manufacturer informed the Investigation that the engine Standard Practice Maintenance Manual (M-0) has now been revised (Revision 1, Change 4, Dated June 2023) and amongst other changes in the revision, cylinder replacement is addressed on pages 10-33, 10-33.1 and 10-33.2.

The revision outlines new standard practices to be adhered to during cylinder removal, including the use of torque plates or spacers in conjunction with applying a specified torque to the affected through-bolt in order to maintain the preload on the crankcase during cylinder removal. Instructions on how to locally manufacture the necessary torque plates are also included.

3. CONCLUSIONS

3.1 Findings

1. The airworthiness certification for the aircraft was valid.

2. The Pilot's licence, ratings and medical certification were valid for the flight being undertaken.

3. Maintenance records indicate that No. 3 and No. 4 cylinders had been removed, repaired and refitted 219 flying hours before the engine failure.

4. The aircraft had undergone two 50-hour and two 100-hour maintenance inspections since the No. 3 and No. 4 cylinders were replaced with no engine anomalies noted.

5. The occurrence flight was the seventeenth flight of the day for Pilot and aircraft, and one more flight was planned.

6. The aircraft took off from RWY 27 at EICL with the Pilot and four Skydivers on board.

7. During climb-out from EICL at approximately 3,500 ft, the Pilot noticed uncharacteristic engine vibrations and a reduction in power.

8. The Pilot made a broadcast on the airfield frequency reporting his intention to return to the airfield due to an engine failure.

9. The setting sun was low and impeded the Pilot's vision and the approach to RWY 27.

10. With some residual engine power available, the Pilot decided to attempt a landing on RWY 09 instead.

11. During the downwind leg for RWY 09, at approximately 450 ft AGL, the aircraft's engine failed completely.

12. The Pilot banked the aircraft approximately 30 to 40 degrees to the left, performing an immediate turn in an attempt to line up with RWY 09.

13. The stall warning horn was heard to activate intermittently during the left turn.

14. When aligned with RWY 09, at an airspeed of approximately 60 kt and with a potential tailwind component, the aircraft had approximately 360 m of runway surface remaining.

15. The Pilot completed an emergency landing and the aircraft touched down with approximately 125 m of grass runway surface remaining.

16. The Pilot applied full left rudder and aileron in an attempt to slow the aircraft on the remaining available runway. Consequently, the aircraft travelled sideways down the airstrip coming to an abrupt halt on a tarmac surface adjacent to a boundary hedge.

17. The Pilot and four Skydivers were uninjured and evacuated the aircraft.

18. The engine failure was due to a fracture of the crankshaft at the No. 2 main journal and bearing location.

19. Three separate major fatigue crack fronts, initiated from heat-induced cracking, due to metal-to-metal frictional overheating, propagated until they coalesced, causing the crankshaft to fracture.

20. The metal-to-metal contact, between the No. 2 main journal and its plain bearing, likely occurred as a result of the oil flow being obstructed due to bearing shift.

3.2 Probable Cause

Engine failure as a result of a fractured crankshaft due to localised heat-induced cracking.

3.3 Contributory Cause(s)

1. Loss of lubrication to the No. 2 main journal likely due to bearing shift.

2. Metal-to-metal contact between the No. 2 main journal and its plain bearing.

3. Localised frictional heating leading to untempering, and subsequent cracking of the crankshaft base material.

4. SAFETY RECOMMENDATIONS

This Report does not sustain any Safety Recommendations.

- END -

Appendix A: Detailed Metallurgical Analysis

A1.1 Crack #1

The nature of the markings on the crack surfaces indicated that Crack #1 was a fatigue crack, which had initiated from two locations, on the outer diameter of MJ #2 (**Figure No. A1**). The features of the primary initiation site had been destroyed by post-fracture damage. At the secondary initiation site, there was a heat-induced longitudinal crack in the outer diameter, approximately 3mm long by 0.45mm deep (**Figure No. A2** and **Figure No. A3**).

Figure No. A1: Crack #1 initiation site on MJ #2

The metallurgist considered that the appearance of the heat-induced crack, at the secondary initiation site, was consistent with having been caused by thermal distress locally, resulting from frictional overheating of the outer diameter (**Figure No. A2**). There was another, similar crack immediately adjacent and running parallel to it (**Figure No. A3**).

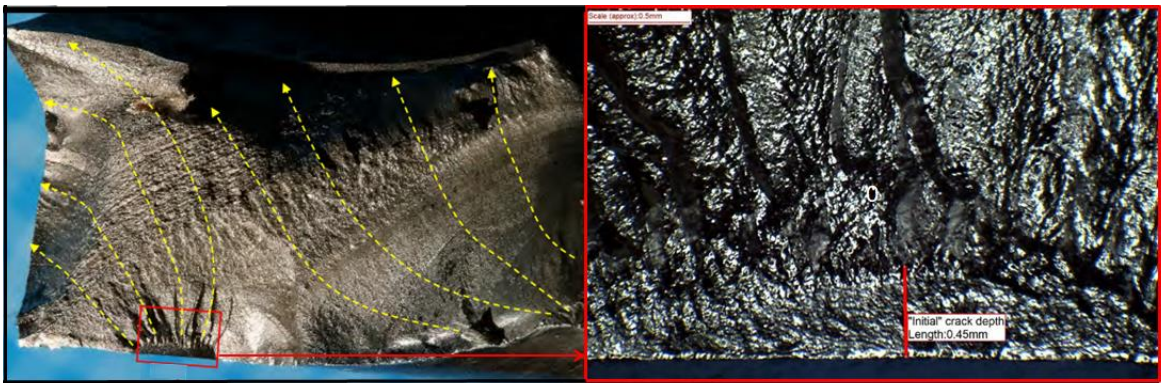

Figure No. A2: Close-up of Crack #1 secondary initiation site on MJ #2

(Primary – Yellow arrows, Secondary – Red Box)

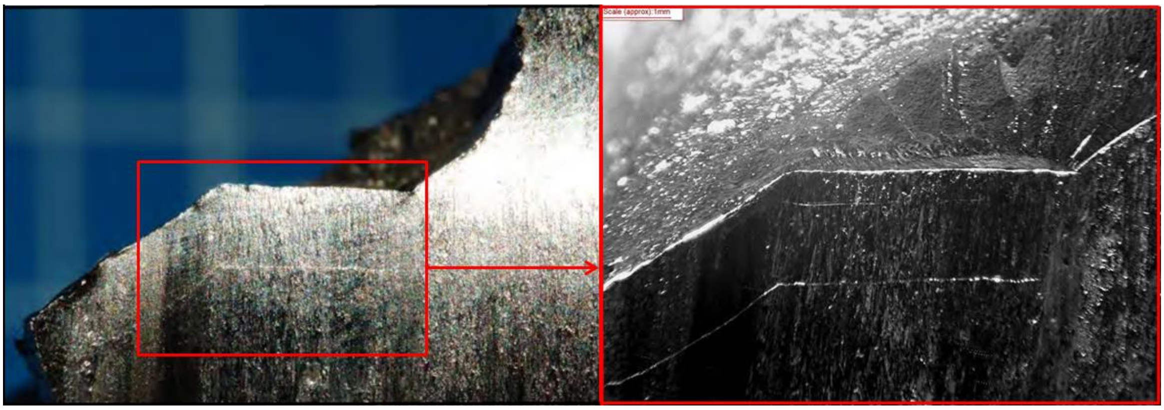

Figure No. A3: Crack #1 Secondary initiation site close-up of MJ #2

A1.2 Crack #2

The nature of the markings on the crack surfaces indicated that Crack #2 was a fatigue crack, which had initiated from a single location on the outer diameter of MJ #2 (**Figure No. A4**). The features of the initiation site had been destroyed by post-fracture damage. The profile of the fracture plane, in the vicinity of the initiation site, was similar to that of Crack #1, in the vicinity of its secondary initiation site. This suggested that Crack #2 had initiated from a heat-induced longitudinal crack, similar to that described for Crack #1 in **Section A1.1**.

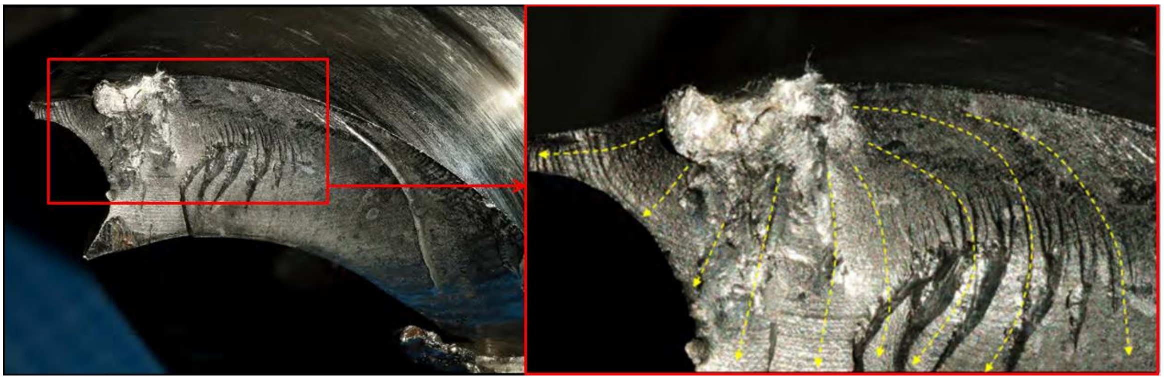

Figure No. A4: Close-up of Crack #2 initiation site on MJ #2

A1.3 Crack #3

The nature of the markings on the crack surfaces indicated that Crack #3 was a fatigue crack which had initiated from a single location on the outer diameter of MJ #2 (**Figure No. A5**). The features of the initiation site had been destroyed by post-fracture damage. The profile of the fracture plane, in the vicinity of the initiation site, was similar to that of Crack #1 in the vicinity of its secondary initiation site. This suggested that Crack #3 had initiated from a heat-induced longitudinal crack, similar to that described for Crack #1 in **Section A1.1**.

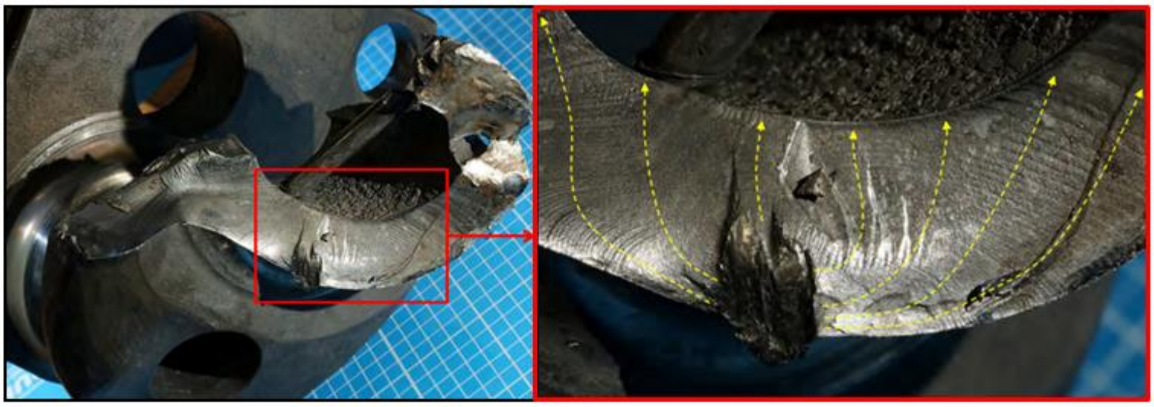

Figure No. A5: Close-up of Crack #3 initiation site on MJ #2

A1.4 Additional Longitudinal Cracks

Several other longitudinal cracks (**Figure No. A6**) were evident on the outer diameter of MJ #2, which were similar in appearance to those described at **Section A1.1** but were remote from the fracture planes. Their appearance suggested that they were also the result of thermal distress, caused by frictional overheating of the outer diameter of MJ #2.

Figure No. A6: Close-up of longitudinal cracks on surface of MJ #2

Short, longitudinal cracks were also present on the cheeks of MJ #2 and RJ #3. Their appearance suggested that they were also the result of thermal distress.

A1.5 Metallography

Etched metallographic sections of the crankshaft were prepared and representative circumferential and longitudinal sections were taken through the surfaces of MJ #1 and MJ #2 for comparison purposes. Both sections showed a bulk microstructure of tempered martensite[18], consistent with hardened and tempered steel. They also showed evidence of surface hardening by nitriding[19], in the form of a dark etched diffusion zone, extending inwards from the surface. However, there were differences at the surfaces of the two journals, as illustrated in **Figure No. A7**.

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[18] **Martensite:** Refers to a very hard steel crystalline structure. Tempering is usually performed after hardening, to reduce some of the excess hardness.

[19] **Nitriding:** A case-hardening process that diffuses nitrogen into the surface of a metal to create a nitride layer.

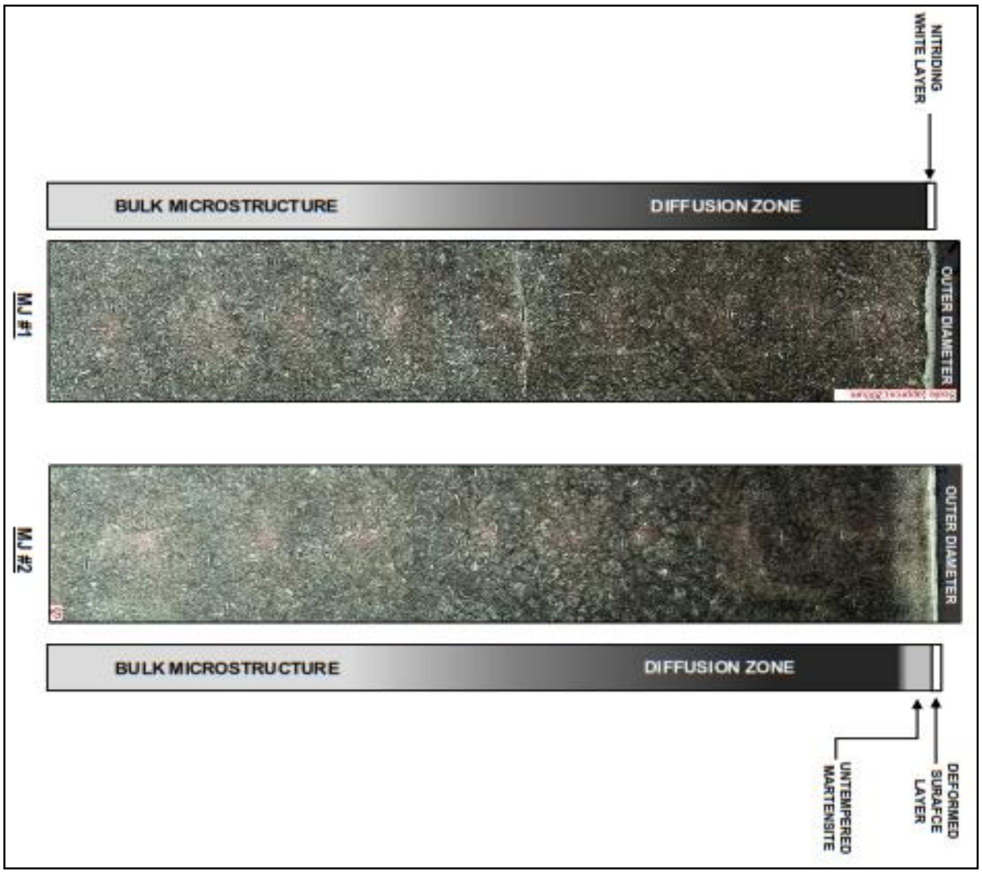

Figure No. A7: Etched metallographic sections through MJ #1 and MJ #2

MJ #1 showed a well-defined white layer at the surface, formed during nitriding. There was also a white etched layer at the surface of MJ #2, but it was identified as not being a nitride white layer but rather as a layer of deformed material, caused by frictional wear on the outer diameter. Beneath it, there was a light etched layer of untempered martensite. This indicated that the frictional wear had generated sufficient heat (temperatures typically above 816 °C [20]) to locally transform the alloy microstructure. High temperature gradients that occurred during the formation of untempered martensite resulted in high levels of residual stress within the affected area.

A1.6 Energy Dispersive X-Ray (EDX) Spectroscopy

EDX Spectroscopy was also performed which showed that the crankshaft material was consistent with AISI 4340 steel as specified by the Engine Manufacturer. The white layer at the surface of MJ #1 showed elevated levels of nitrogen, which confirmed that it had been formed during nitriding. The deformed layer at the surface of MJ #2 showed elevated levels of aluminium and silicon, which had most likely been transferred from the plain bearing.

[20] **816°C**: The minimum temperature at which the microstructure of the crankshafts low alloy steel will change to a crystal structure known as austenite.

A1.7 Hardness Testing

Hardness testing was also performed, and the bulk alloy harnesses of MJ #1 and MJ #2 were 77 and 76 HR15N[21] respectively. This approximates to an ultimate tensile strength of 1,035 Megapascal (MPa). The microhardness profile of MJ #1 was consistent with surface hardening by nitriding. The hardening effect of the nitriding process extended for some distance beneath the white layer. In comparison, MJ #2 showed that frictional heating on its outer diameter had affected its hardness profile. The nitriding white layer was absent from the surface but there was a white etched layer of deformed material, with a light etched layer of untempered martensite beneath it. The microhardness values within the diffusion zone for MJ #2 were erratic.

- END -

[21] **HR15N:** Rockwell Hardness Test

In accordance with Annex 13 to the Convention on International Civil Aviation, Regulation (EU) No. 996/2010, and Statutory Instrument No. 460 of 2009, Air Navigation (Notification and Investigation of Accidents, Serious Incidents and Incidents) Regulation, 2009, the sole purpose of this investigation is to prevent aviation accidents and serious incidents. It is not the purpose of any such investigation and the associated investigation report to apportion blame or liability.

A safety recommendation shall in no case create a presumption of blame or liability for an occurrence.

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