AIRCRAFT ACCIDENT REPORT AND EXECUTIVE SUMMARY

				Reference:		CA18/2/3/10003	
Aircraft Registration	**ZS-CKM**		**Date of Accident**	13 May 2021		**Time of Accident**	1420Z
Type of Aircraft	PA-32RT-300T			**Type of Operation**		Private (Part 91)	
Pilot-in-command Licence Type		Airline Transport Pilot Licence (ATPL)		**Age**	32	**Licence Valid**	Yes
Pilot-in-command Flying Experience		**Total Flying Hours**		2 327.4		**Hours on Type**	87.3
Last Point of Departure	Port Elizabeth Aerodrome (FAPE), Eastern Cape Province						
Next Point of Intended Landing	Pietermaritzburg Aerodrome (FAPM), KwaZulu-Natal Province						
Damage to Aircraft	Substantial						
Location of the accident site with reference to easily defined geographical points (GPS readings if possible)							
Umtentweni, about 50nm south-west of FAPM at GPS S 30°33'11.1" E030°17'20.2", and at an elevation of 1 411 feet							
Meteorological Information	Wind direction: 90°; Wind speed: 10kts; Visibility: 10km; Temperature: 22°C; Cloud cover: CAVOK; Dew point: 7°C						
Number of People On-board	2+1	**Number of People Injured**	0	**Number of People Killed**	0	**Other (On Ground)**	0
Synopsis							

On 13 May 2021, two pilots and a passenger on-board a PA-32RT-300T aircraft registered ZS-CKM took off from Port Elizabeth Aerodrome (FAPE) with the intention to land at Pietermaritzburg Aerodrome (FAPM). The flight was conducted under instrument flight rules (IFR) by day and under the provisions of Part 91 of the Civil Aviation Regulations (CAR) 2011 as amended. The flight plan was filed for the flight.

About two hours after take-off, the engine started to lose power and, subsequently, stopped. The pilot-in-command (PIC) executed a force landing on a gravel road in Umtentweni, located 50 nautical miles (nm) south-west of FAPM. During the landing roll, both wings of the aircraft collided with the street sign poles which were positioned on either side of the gravel road. As a result, both wing tips were severed, and the ailerons detached. The aircraft was substantially damaged; however, the occupants were not injured during the accident sequence.

After the accident, the engine was removed from the aircraft and was sent to an approved engine workshop for inspection. After the engine was disassembled and inspected, it was found that the engine crankshaft had failed. It was then sent for metallurgical testing. The metallurgical test results revealed two primary fractures that progressed due to predominant fatigue in the web section of the crankshaft during operation.

Probable Cause and Contributory Factors

The crankshaft broke at two points during flight due to fatigue, resulting in engine stoppage and the subsequent unsuccessful forced landing on the gravel road.

Contributing Factor

The crankshaft was not inspected for wear and condition at every 2000 hours or at 12 years as per the manufacturer's recommendation.

SRP Date	20 September 2022	Publication Date	22 September 2022

Occurrence Details

Reference Number	**:** CA18/2/3/10003
Occurrence Category	**:** Category 2
Type of Operation	**:** Private (Part 91)
Name of Operator	**:** Michael Christiaan Erasmus
Aircraft Registration	**:** ZS-CKM
Aircraft Make and Model	**:** Piper PA-32RT-300T
Nationality	**:** South African
Place	**:** Umtentweni 50nm SW FAPM GPS S 30˚33´11.1˝ E030˚17´20.2˝
Date and Time	**:** 13 May 2021 and 1420Z
Injuries	**:** None
Damage	**:** Substantial

Purpose of the Investigation:

In terms of Regulation 12.03.1 of the Civil Aviation Regulations (CAR) 2011, this report was compiled in the interest of the promotion of aviation safety and the reduction of the risk of aviation accidents or incidents and ***not to apportion blame or liability****.*

All times given in this report are Co-ordinated Universal Time (UTC) and will be denoted by (Z). South African Standard Time is UTC plus 2 hours.

Investigation Process:

The Accident and Incident Investigations Division (AIID) of the South African Civil Aviation Authority (SACAA) was notified of the occurrence on 13 May 2021 at 1450Z. The investigator did not dispatch to the accident site but conducted the investigation remotely. The occurrence was classified as an accident according to Part 12 of the CAR 2011 and ICAO STD Annex 13 definitions. Notifications were sent to the State of Registry/Operator/Design/Manufacture in accordance with Part 12 of the CAR 2011 and ICAO Annex 13 Chapter 4. The States did not appoint an accredited representative and advisor.

Notes:

1. Whenever the following words are mentioned in this report, they shall mean the following:

- *Accident — this investigated accident*
- *Aircraft — the PA-32RT-300T involved in this accident*
- *Investigation — the investigation into the circumstances of this accident*
- *Pilot — the pilot involved in this accident*
- *Report — this accident report*

2. Photos and figures used in this report were taken from different sources and may have been adjusted from the original for the sole purpose of improving clarity of the report. Modifications to images used in this report were limited to cropping, magnification, file compression; or enhancement of colour, brightness, contrast; or addition of text boxes, arrows or lines.

Disclaimer:

This report is produced without prejudice to the rights of the AIID, which are reserved.

Table of Contents

Abbreviation	Description
°	Degrees
'	Minutes of co-ordinates
"	Seconds of co-ordinates
AIID	Accident and Incident Investigations Division
AMO	Aircraft Maintenance Organisation
AOC	Air Operating Certificate
ATPL	Airline Transport Pilot Licence
C	Celsius
CAR	Civil Aviation Regulation
CAVOK	Ceiling and Visibility OK
CoA	Certificate of Airworthiness
CoR	Certificate of Registration
CPL	Commercial Pilot Licence
CVR	Cockpit Voice Recorder
E	East
FAPM	Pietermaritzburg Aerodrome
FAPE	Port Elizabeth Aerodrome
FDR	Flight Data Recorder
Ft	Feet
GPS	Global Positioning System
hPa	Hectopascal
IFR	Instrument Flight Rules
Kts	Knots
Lb	Pounds
m	Metres
MPI	Mandatory Periodic Inspection
NM	Nautical Miles
PIC	Pilot-in-command
PPL	Private Pilot Licence
QNH	Query Nautical Height (Height Above Sea Level)
RPM	Revolutions per Minute
S	South
SACAA	South African Civil Aviation Authority
SAWS	South African Weather Service
UTC	Universal Time Co-ordinated
Z	Zulu

1. FACTUAL INFORMATION

1.1. History of Flight

1.1.1 On the afternoon of 13 May 2021 at approximately 1230Z, a Piper PA-32RT-300T aircraft with registration ZS-CKM took off on a private flight from Port Elizabeth Aerodrome (FAPE) with the intention to land at Pietermaritzburg Aerodrome (FAPM). On-board the aircraft were a pilot-in-command (PIC), a co-pilot and a passenger. The flight was conducted under instrument flight rules (IFR), but visual meteorological conditions (VMC) prevailed at the time of flight. The flight was conducted under the provisions of Part 91 of the Civil Aviation Regulations (CAR) 2011 as amended. The flight plan was filed for the flight.

1.1.2 The co-pilot and the pilot-in-command (PIC) conducted a pre-flight inspection before departure, and uplifted 92 US gallons of Avgas before the flight. The PIC stated that they departed FAPE using Runway 26 and had, initially, climbed to flight level 090 (FL090). Thereafter, they climbed to FL110. The departure, climb and cruise phases progressed as expected. At approximately 1425Z, two hours and five minutes into the flight before top of descent, the crew stated that they heard a loud noise coming from the engine, as well as noticed severe vibration and a reduction in engine power. The crew immediately set course for the nearest airport, which was Margate Aerodrome (FAMG), whilst they were carrying out fault-finding procedures to rectify the problem. However, the exercise produced no positive results. The engine lost power before it finally stopped. The crew then identified a small road in Umtentweni on which they could perform a forced landing. Thereafter, they informed the passenger of the situation at hand and instructed her to stow all loose objects and fasten her seat belt.

1.1.3 The PIC stated that before touch down, they unlocked the doors and assumed the brace position. The aircraft touched down and remained centred on the road. However, during the landing roll, both the left- and the right-side wing tips struck two road sign poles which were approximately 20 metres (m) apart; the wing tips were severed, and the ailerons got detached in the process. The crew managed to maintain directional control until the aircraft came to a stop.

1.1.4 All occupants on-board were not injured in the accident sequence and the aircraft sustained substantial damage.

1.1.5 The accident occurred during daylight at Global Positioning System (GPS) co-ordinates determined to be S30°33'11.1" E030°17'20.2", at an elevation of 1 411 feet.

Figure 1: The accident location. (Source: Google Earth)

1.2. Injuries to Persons

Injuries	Pilot	Crew	Pass.	Total On-board	Other
Fatal	-	-	-	-	-
Serious	-	-	-	-	-
Minor	-	-	-	-	-
None	2	-	1	3	-
Total	2	-	1	3	-

Note: Other means people on the ground.

1.3. Damage to Aircraft

1.3.1 The aircraft sustained substantial damage during the accident sequence.

Figure 2: The aircraft at the accident site after it had come to a stop. (Source: Pilot)

1.4. Other Damage

1.4.1 Minor damage to the two road sign poles, approximately 20 metres (m) apart, which were struck by the aircraft's wing tips.

Figure 3: Minor damage to the road sign poles.

1.5. Personnel Information

1.5.1 Pilot-in-command (PIC):

Nationality	South African	Gender	Male	Age	32
Licence Type	Airline Transport Pilot Licence (ATPL)				
Licence Valid	Yes	Type Endorsed	Yes		
Ratings	Night rating, Instrument rating and Instructor Grade II				
Medical Expiry Date	30 November 2021				
Restrictions	None				
Previous Accidents	None				

Note: Previous accidents refer to past accidents the pilot was involved in, when relevant to this accident.

1.5.1.1 The PIC was initially issued an Airline Transport Pilot Licence (ATPL) on 6 June 2019. His last licence validation was carried out on 9 June 2020 with an expiry date of 30 June 2021.

1.5.1.2 The PIC was issued a Class 1 aviation medical certificate on 26 November 2020 with an expiry date of 30 November 2021.

Flying Experience:

Total Hours	2 327.4
Total Past 24 Hours	2.4
Total Past 7 Days	11
Total Past 90 Days	80.7
Total on Type Past 90 Days	24.3
Total on Type	87.3

1.5.2 Co-pilot:

Nationality	South African	Gender	Male	Age	61
Licence Type	Private Pilot Licence (PPL)				
Licence Valid	Yes	Type Endorsed	Yes		
Ratings	Night rating				
Medical Expiry Date	30 June 2021				
Restrictions	To wear corrective lenses				
Previous Accidents	None				

Note: Previous accidents refer to past accidents the pilot was involved in, when relevant to this accident.

1.5.2.1 The co-pilot was initially issued a Private Pilot Licence (PPL) on 27 December 1993. His last licence validation was on 9 June 2020 with an expiry date of 30 June 2021.

1.5.2.2 He was issued a Class 2 aviation medical certificate on 4 June 2020 with an expiry date of 30 June 2021.

Flying Experience:

Total Hours	721.2
Total Past 24 Hours	6.6
Total Past 7 Days	8.8
Total Past 90 Days	38.1
Total on Type Past 90 Days	28
Total on Type	80.5

1.6. Aircraft Information

1.6.1 The Piper PA-32R is a six-seat, high-performance single engine, all-metal fixed-wing aircraft produced by Piper Aircraft of Vero Beach, Florida. The design type began as the Piper Lance, a retractable-gear version of the Piper Cherokee Six.

Airframe:

Manufacturer/Model	Piper Aircraft Corporation / PA-32RT-300T	
Serial Number	32R-7887114	
Year of Manufacture	1978	
Total Airframe Hours (At Time of Accident)	4 106.78	
Last Inspection (Date & Hours)	16 October 2020	4 034.73
Airframe Hours Since Last Inspection	72.05	
CRS Issue Date	15 October 2020	
C of A (Issue Date & Expiry Date)	24 April 2016	30 April 2022
C of R (Issue Date) (Present Owner)	1 August 2019	
Operating Category	Standard Normal Category (Aeroplane)	
Type of Fuel Used	Avgas	
Previous Accidents	None	

Note: Previous accidents refer to past accidents the aircraft was involved in, when relevant to this accident.

1.6.2 According to available information, the aircraft was first registered as ZS-NVW and, in 2004, it was ferried to Namibia and was re-registered as V5-GCN (Namibian registration). In 2016, the aircraft was ferried back to South Africa and was re-registered as ZS-CKM. The aircraft was last issued a Certificate of Release to Service (CRS) on 15 October 2020 with an expiry date of 15 October 2021 or at 4 130.71 airframe hours, whichever occurs first.

Engine:

Manufacturer/Model	Textron Lycoming
Serial Number	L-5536-61A
Part Number	TIO-540-S1AD
Hours Since New	4 106.78
Hours Since Overhaul	1 151.00

1.6.3 The information below was sourced from the airframe and engine logbooks. The service history of the relevant engine, serial no L-5536-61A, revealed the following:

- The last engine overhaul was carried out by CRS #RF4R490M in the United States of America on 20 January 2000 at 2 924 engine hours. While in the US, the engine was test-run for 2 hours and was preserved for short-time storage and, later, shipped to South Africa (see Export Certificate of Airworthiness attached as Annexure A). Following shipment, the engine serial no L-5536-61A was installed on the ZS-NVW aircraft. The engine was never removed from the aircraft during change of ownership and re-registration.

- According to the compliance records in the logbook relating to Service Bulletins (SBs) and Airworthiness Directives (ADs), the crankshaft inspection ADs were signed out as "Not Applicable" either by engine type or serial number; therefore, these ADs were not complied with. The engine "blow-by" was carried out at every mandatory periodic inspection (MPI). The last borescope inspection was carried out in 2019, and no anomalies were found.

1.6.4 According to the engine manufacturer, an engine overhaul should be carried out at every 2000 hours or 12-year mark. During the overhaul, the crankshaft should be inspected for condition and wear limits and measured to determine if it is still within limits. All the wear limits are stated in the overhaul manual. A crankshaft that is out of limit should be replaced.

Information was taken from the South African Civil Aviation Authority Aeronautical Information Circular (AIC) 18.19, initially issued on 15 September 2001 and revised on 22 December 2006.

- *Maintenance Requirements for engines 12 years or older: -*
    - *These requirements will be applicable to Textron Lycoming and Teledyne Continental reciprocating aircraft engines that have reached a 12-year calendar life, but not exceeded the hourly limitation imposed, and shall be carried out to ensure continued compliance with the airworthiness standards for the engine:*

(a) All such engines, which have not been overhauled for the past 12 years or more, or upon reaching the 12-year calendar life period, shall be inspected and all aircraft maintenance organisations (AMOs) shall record this in the relevant logbook. This entry will state that all Instructions for Continuous Airworthiness (lCA) requirements (Certification Requirements and ADs) have been complied with.

(b) The engine must be inspected for defects and blow-by, and a boroscope inspection carried out on all cylinders. The blow-by and boroscope inspection must be within acceptable limits and certified as such in the applicable logbook. The engine must conform with all relevant Airworthiness Directives.

(c) All fuel carrying lines and oil leaks must be investigated and rectified where necessary. Seals and hoses requiring replacement are to be replaced.

(d) Engine mounted components and accessories requiring overhaul at the same hourly or calendar intervals as the engine, shall be overhauled at the same time as the engine, unless otherwise specified by the component or accessory manufacturer, whichever is the shortest period.

(e) The Commissioner for Civil Aviation reserves the right to review this policy and these conditions on the basis of new ADs which the manufacturing state may issue in relation to the continuing airworthiness requirements of these engines or a significant safety case based upon recorded aviation safety data involving these engines.

- On 1 June 2018 at 3 979.5 engine hours, the engine's 100-hour MPI was carried out and a gear tooth was found inside of the oil sump suction filter.

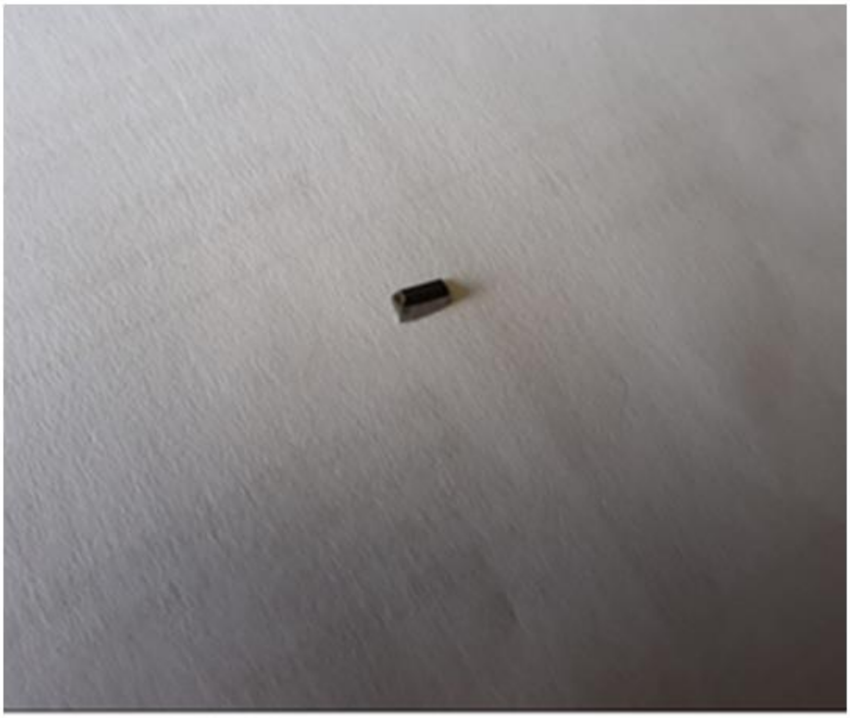


Figure 4: The gear tooth found inside an oil sump filter. (Source: AMO)

- The engine was removed for further (gears) inspection by an approved AMO. After the gear box was stripped down and inspected; no broken or damaged gears were found. The engine was then reassembled and refitted to the ZS-CKM on 29 June 2018. During the engine run, oil leaked from the engine and, therefore, it was taken back to the engine shop. According to the AMO, the engine was dismantled, cleaned and inspected in accordance with Overhaul Manual 60294-7-14 and Service Table of Limits SSP1776-4-PT1. The engine was assembled using new gaskets and seals. The crankshaft was not stripped. An Airworthiness Directive (AD) (2002-19-03) which required crankshaft material testing was not carried out because it was not applicable to the engine and crankshaft serial number. The engine was re-fitted to the ZS-CKM.

Figure 5: The serviceable gears from the ZS-CKM aircraft.

Propeller:

Manufacturer/Model	Hartzell
Serial Number	PA1193B
Part Number	HC-E2YR-1BF
Hours Since New	1 119.04
Hours Since Overhaul	264.86

i. According to the PIC questionnaire response, the aircraft was refuelled with 92 US gallons of Avgas on 13 May 2021. The aircraft had 47 US gallons remaining at the time of the accident.

ii. The aircraft's certified maximum take-off weight is 3600 pounds (lb). On the day of the accident, the aircraft was approximately 3281.2lb, which was below the maximum certificated take-off weight of 3600lb.

Empty Weight	2282.2lb
Crew	651lb
Passenger	145lb
Fuel	203lb
Total	3281.2lb
MTOW	3600lb

1.7. Meteorological Information

1.7.1 The weather information entered in the table below was obtained from the pilot questionnaire.

Wind Direction	90°	Wind Speed	10kts	Visibility	+10km
Temperature	22°C	Cloud Cover	CAVOK	Cloud Base	Nil
Dew Point	7°C				

1.7.2 The METAR for FAPM between 1400Z and 1500Z on 13 May 2021 was as follows:
FAPM 131400Z AUTO 06005KT //// // ////// 26/07 Q1017
FAPM 131500Z AUTO 09003KT //// // ////// 24/10 Q1017

1.7.3 FAPM is located 52 nautical miles (NM) south of the accident site.

1.8. Aids to Navigation

1.8.1 The aircraft was equipped with standard navigational equipment as approved by the Regulator (SACAA) for the aircraft type. There were no records indicating that the navigation system was unserviceable prior to the accident flight.

1.9. Communication

1.9.1 The aircraft was equipped with standard communication equipment as approved by the Regulator for the aircraft type. There was no record indicating that the communication system was unserviceable prior to the accident.

1.10. Aerodrome Information

1.10.1 The accident did not occur at or near an aerodrome, but in Umtentweni, approximately 50nm south-west of FAPM, which is the nearest aerodrome.

1.11. Flight Recorders

1.11.1. The aircraft was neither fitted with a cockpit voice recorder (CVR) or a flight data recorder (FDR), nor was it required by regulation to be fitted.

1.12 Wreckage and Impact Information

1.12.1 The pilots executed an emergency landing on a gravel road. The aircraft remained centred on the road and, during the landing roll, both wing tips struck two road sign poles on the opposite sides of the road which were approximately 20m apart.

Figure 6: The aircraft at the accident site where it came to a stop. (Source: Pilot)

1.12.2 Both the left- and the right-wing tips hit the road sign poles on each side of the road, approximately 20m apart.

Figure 7: The severed left- and right-side wing tips. (Source: Pilot)

1.12.3 Both the left and the right-side ailerons seperated from the outboard side of the wings (see Figures 8 and 9).

Figure 8: The damaged left-side wing and aileron. (Source: Pilot)

Figure 9: The damaged left-side wing. (Source: Pilot)

1.13 Medical and Pathological Information

1.13.1 Not applicable.

1.14 Fire

1.14.1 There was no evidence of a pre- or post-impact fire.

1.15 Survival Aspects

1.15.1 The accident was considered survivable because the cockpit structure was still intact, and all occupants had made use of the aircraft's safety harnesses.

1.16 Tests and Research

1.16.1 Investigation Results (Source: Failure Analysis Report. Document Number FA-007-06-21: Compiled by Laboratory for Microscopy & Microanalysis.)

After the accident, the engine was removed from the aircraft and was sent to an approved engine workshop for inspection where an engine strip was carried out on 26 May 2021. During this inspection, it was found that the engine crankshaft, with Serial Number LW15302, had broken and was sent for metallurgical testing (see Photo 3). The detailed report of the metallurgical testing is attached as Annexure B.

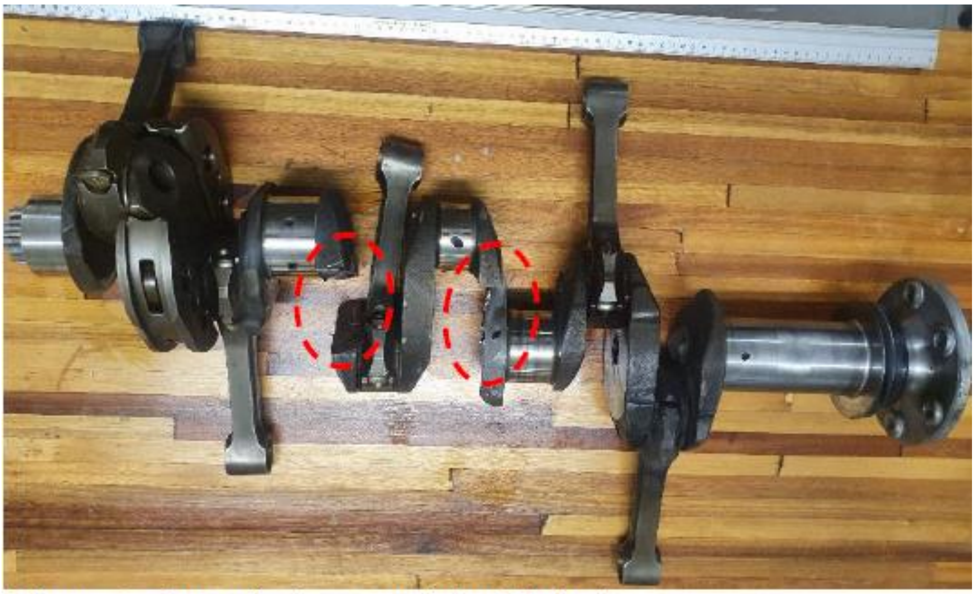


Photo 3: Supplied assembly (Digital)

- *On-site Inspection*

The engine was inspected after a partial teardown. The crankcase revealed severe damages attributable to the fractured crankshaft during operation.

The oil pump revealed no clear signs of failure during operation (Photo 4).

Photo 4: Oil pump condition[4]

The main sleeve bearings (Diagram 2) revealed signs of wear, metal impregnation and temperature exposures (Photo 5).

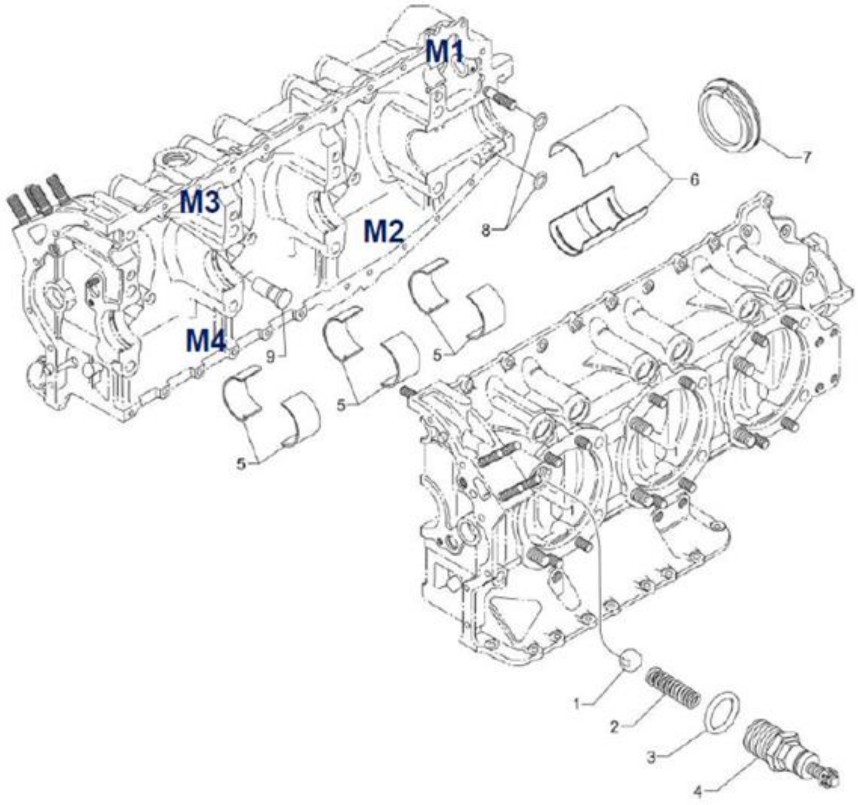


Diagram 2: Main bearings- and crankcase layout

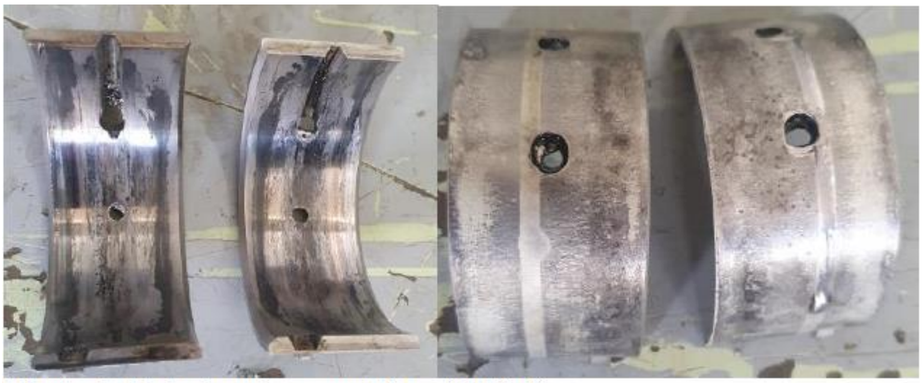


Photo 5: Main bearing condition (Digital)

- *Laboratory Inspection*

Visual inspection of the supplied crankshaft revealed two fractures marked A and B (Photos 7 and 8) within the web sections between the adjacent main bearings M2 and M3 and piston conrod positions 3 and 4 (Photo 6; Diagrams 1 and 3). Both fractured surfaces revealed signs corresponding with a fatigue mode of failure and initiated within the radius sections of the main bearings M2 and M3, respectively (Photos 7 and 8, red circles). The fractures progressed through the web sections in the directions as indicated (yellow arrows) until final fast fracture.

The 'benchmark' spacing, level of secondary damage and surface contamination indications suggest that fracture A initiated prior, or progressed at a higher rate, than fracture B.

Both the main bearing contact surfaces M2 and M3 (Photos 7 and 8, yellow arrows) revealed slight signs of wear and temperature exposure. This is not consistent with a total bearing seizure scenario and can be considered as collateral damages induced during the crankshaft failure sequence.

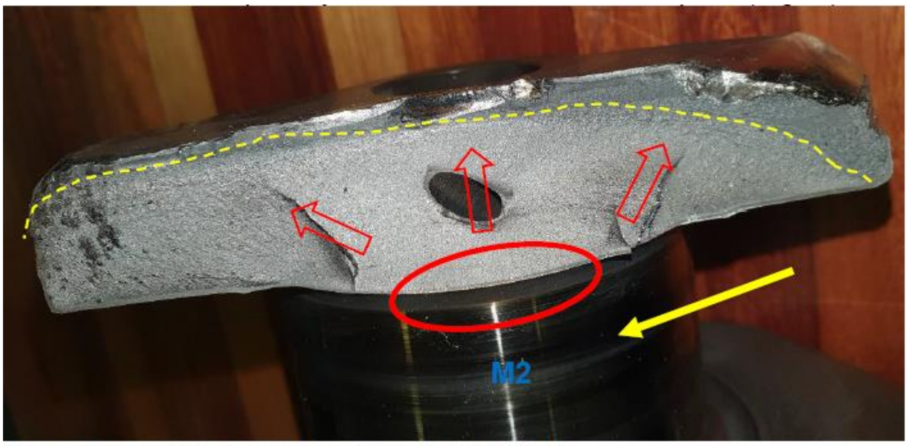


Photo 7: Fracture A, surface geometry (Digital)

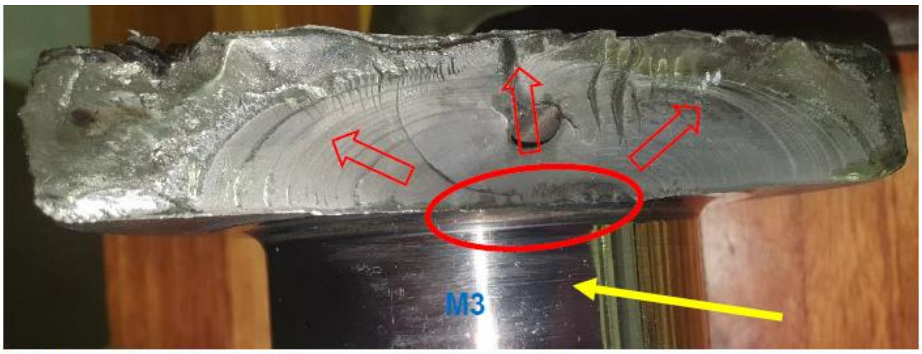


Photo 8: Fracture B, surface geometry (Digital)

A qualitative Non-destructive Testing (NDT) Dye-Penetrant Inspection (DPI) revealed extensive micro-fracture initiations around the main bearing (M3) contact surface circumference at fracture position B (Photo 10, red circle). This is indicative of severe stress exposure to the crankshaft in the radial direction during rotation and not related to a typical bearing failure (seizure, break-up, etc.).

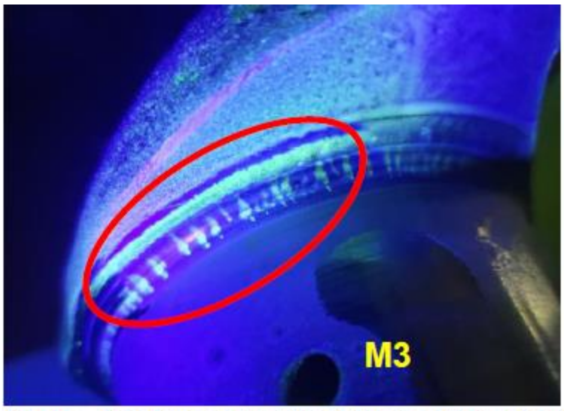


Photo 10: Dye-penetrant inspection result (Digital)

The big-end connecting rods C1 and C2 (Diagram 1; Photo 6) and bearings revealed signs of high temperature exposures, excessive wear and imminent seizure (Photo 9). This could be considered as collateral damages induced during the failure sequence of the crankshaft due to the blockage of the oil feed lines.

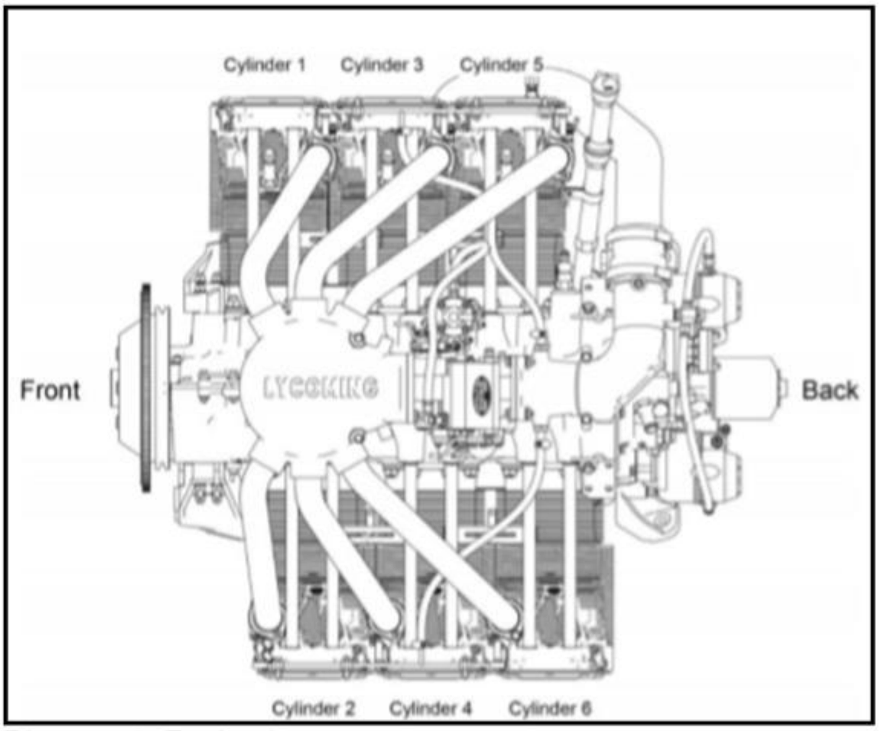


Diagram 1: Engine layout

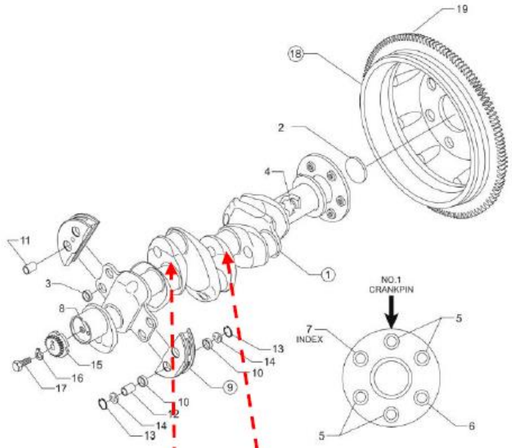


Diagram 3: Crankshaft and related parts

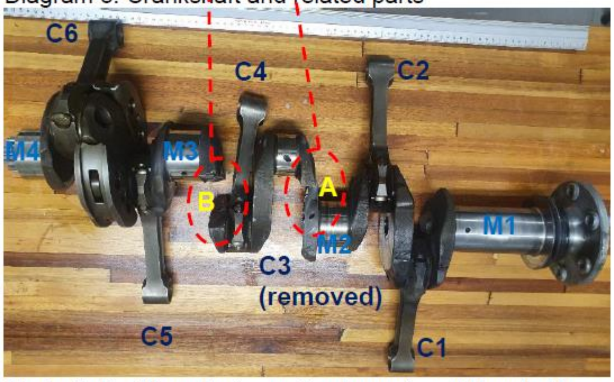


Photo 6: Position of primary fractures A and B and other parts (Digital)

Photo 9: Connecting rod C1 condition (Digital)

Discussion and Conclusions:

Note 1: The conclusions are based on the investigation results obtained from the supplied parts/components and information only. All information supplied to this investigation from other parties is considered factual.

The investigation revealed two primary fractures, A and B, initiated, and progressed with predominant fatigue mode features within the web sections of the crankshaft during operation.

Secondary micro-fractures were noted adjacent to the primary fracture positions. These micro-fractures in turn induced multiple fatigue fracture initiations. The most probable cause towards the formation of these micro-fractures could be the incident at Hobbs time 1513.40h (ref. p.1.3.1). Dislocation of a main bearing would require dimensional changes brought about by one or more of the following: loss of crankcase bolt torque, excessive sleeve bearing wear, collapse of the crankcase bearing journal or incorrect fitment. None of the aforementioned were confirmed by this investigation. However, this dimensional change at the main bearing position/s will inevitably influence the applied load conditions on the rotating crankshaft during operation. This will allow for a variable radial stress exposure over the length of the crankshaft, but most prominent at the centre section where the primary fractures initiated.

The fracture surface analysis results suggest that Fracture A initiated prior, or progressed at a higher rate, than Fracture B. The most probable sequence is that micro-fractures initiated within the radius sections of both A and B and on reaching the critical flaw size, A progressed first/faster allowing for increased crankshaft radial movement that in turn influenced and increased the progression rate at B.

Foreign deposits originating from the sleeve bearing material and operating environment confirm the existence of both the primary fractures A and B for an undetermined period.

1.17 Organisational and Management Information

1.17.1 This was a private flight conducted under the provisions of Part 91 of the Civil Aviation Regulations (CAR) 2011 as amended.

1.17.2 The AMO which carried out the last maintenance inspection on the aircraft prior to the accident flight had an AMO-approval certificate issued on 1 December 2020 with an expiry date of 30 November 2021.

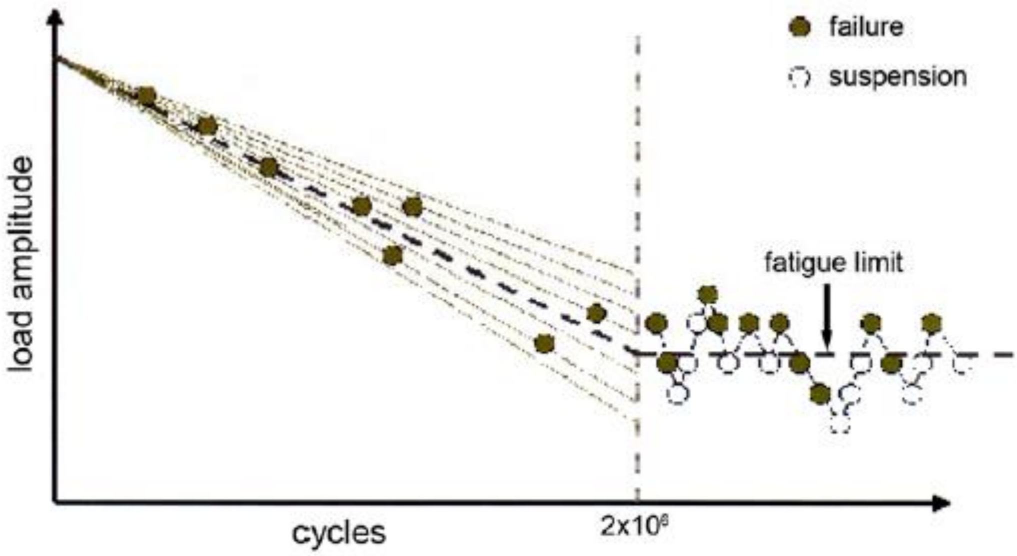
1.18 Additional Information

1.18.1 Australian Transport Safety Board (ATSB) Aviation Research and Analysis Report-B20070191 research focused on aircraft reciprocating engine failures (Source: https://www.atsb.gov.au/media/29980/b20070191.pdf pg. 189-195)

Crankshaft fatigue failure

Crankshafts, regardless of the end application of the engine, are designed to have an operational life not limited by fatigue. The complex interrelationships between loads, geometric stress concentrators, residual stress, surface finish, surface hardening, and material results in scatter in fatigue behaviour. Safety factors are applied to ensure that, for a particular crankshaft design, the maximum alternating stress from engine, operation does not intersect the distribution of crankshaft fatigue endurance strength.

Figure 8.72: Schematic showing the scatter in the relationship between alternating stress magnitude and number of alternating stress cycles for a crankshaft (Lee and Morrissey, 2001)



Two dominant fatigue failure modes have been identified by the designers of crankshafts (Piraner, Pflueger and Bouthier, 2002):

• fatigue through a crankweb, associated with bending of the crank throw in its plane, with crack initiation occurring at a main or crank journal fillet; and

• fatigue through a connecting-rod journal, associated with alternating shear stresses generated by throw torsion, with fatigue cracking initiating at an oil hole.

The initiation and propagation of fatigue cracks in a crankshaft is not simply a matter restricted to the material from which the crankshaft is manufactured. It is a matter of all factors that affect the magnitude of crankshaft alternating stresses, and the crankshaft endurance strength.

Crankshaft alternating stress:

External loads

The major loads imposed on a crankshaft during operation are loads created by combustion gas pressure and the loads created by the inertia of rotating and reciprocating assemblies. These loads create bending and torsional stresses in the crankshaft journals and crankwebs. The maximum stress in the crankshaft is developed when the engine is operated in a manner that results in maximum combustion chamber gas pressure and/or maximum piston speed.

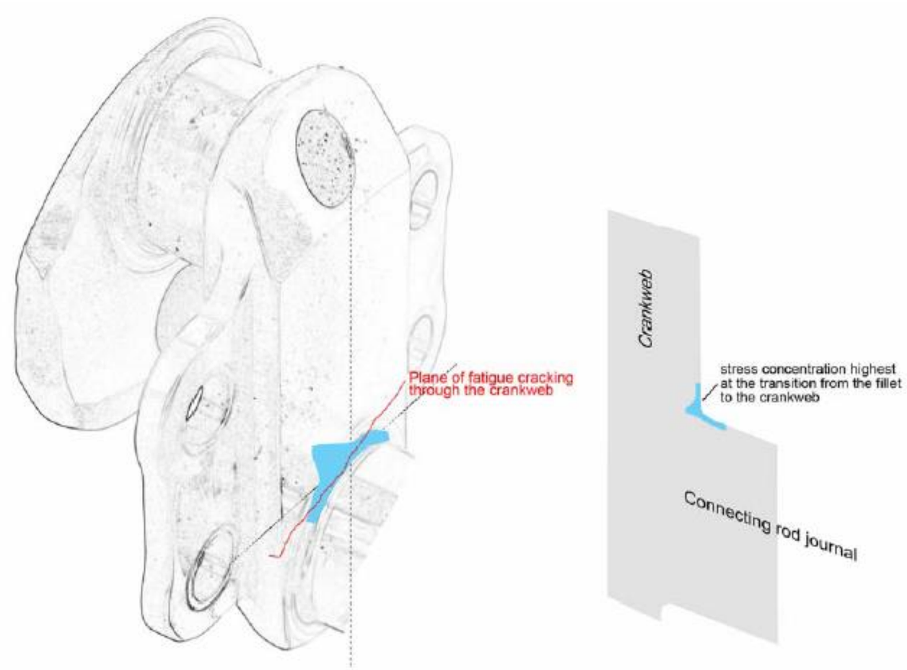
A feature of the layout of horizontally-opposed engines – the placement of a main bearing between two connecting-rod journals – makes crankshaft bending a critical loading condition, see figure 8.72 above. The magnitude of bending stresses in crankwebs is strongly influenced by the placement of journals (Taylor, 1999, vol.2, pp.494-495). Bending stresses are increased as the length of the crankweb between neighbouring journals is increased.

Torsional stresses arise from the action of the gas pressure loads on the cranks and the transmission of torque to the engine output flange and accessory drivetrain. A special loading case that is considered during design, and thoroughly tested during engine certification is that of torsional resonance. Torsional resonance is a function of the frequency of gas pressure impulses and the elastic properties of the crankshaft.

Stress concentration

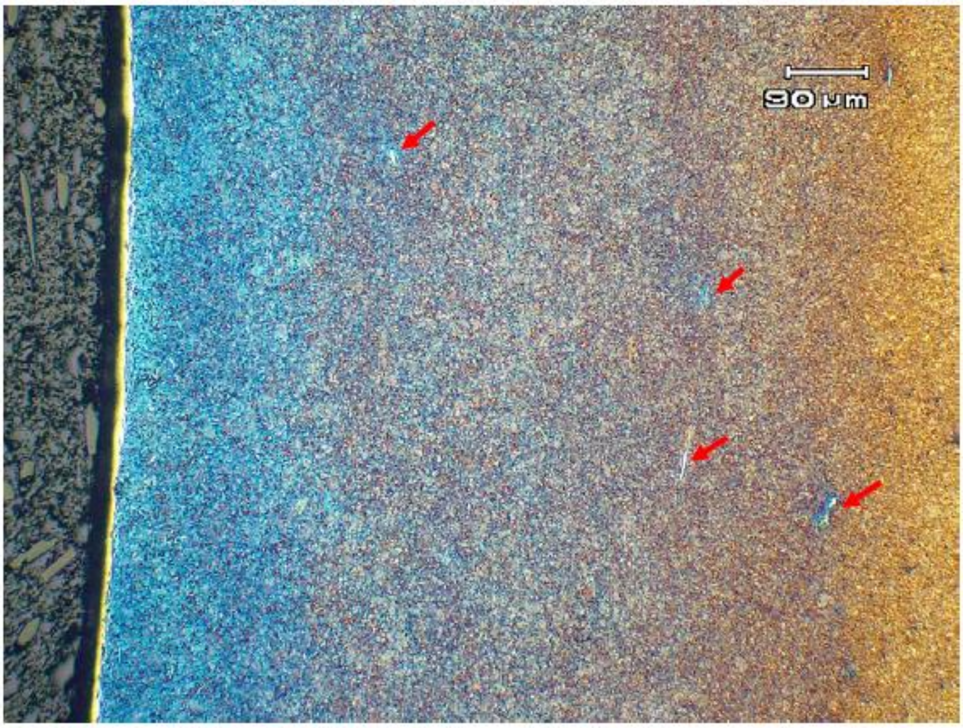
The distribution of stress developed within a crankshaft, through crankshaft bending and torsional, is not uniform (Taylor, 1999, vol.2, pp.496-498). Stress gradients are formed under bending and torsion loading. The stress decreases in magnitude from the surface to the centre of the component. The form of a crankshaft results in non-uniform distributions of stress. Torsional stresses are concentrated in the journals and bending stresses are concentrated in the transitions between the journals and crankwebs. For the case of crankshaft bending, the distribution of bending stress in the journal fillet region is not uniform around the circumference of the fillet or around the fillet radius, figures 8.74 and 8.80. The distribution of bending stress is influenced by detailed geometry and the timing of the maximum load with respect to the angular position of the crankshaft.

Figure 8.74: Schematic showing the distribution of crankweb bending stress at the forward fillet of a No.6 connecting rod journal



The orientation of the plane of fatigue cracking is related to the angular position of the crankweb at the time of maximum combustion pressure; for normal operation the peak pressure is developed approximately 20° after top centre.

Figure 8.80: Metallographic section through the No.1 connecting-rod journal fillet



The fillet surface is at the left of the micrograph. The depth of nitriding can be distinguished by the colourisation; the core material is at the right (straw/gold). Several non-metallic inclusions are evident (arrowed).

1.19 Useful or Effective Investigation Techniques

1.19.1 None.

2. ANALYSIS

2.1. General

From the available evidence, the following analysis was made with respect to this accident. This shall not be read as apportioning blame or liability to any particular organisation or individual.

2.2. Analysis

A. Crew

2.2.1 The PIC was initially issued an Airline Transport Pilot Licence (ATPL) on 6 June 2019 with the aircraft type endorsed on it. The pilot is also the owner of the aircraft. His last ATPL validation was on 9 June 2020 with an expiry date of 30 June 2021. The pilot had a total of 2 327.4 flight hours and 87.3 of those hours were on the aircraft type. He had a Class 2 aviation medical certificate issued on 4 June 2020 with an expiry date of 30 June 2021.

The co-pilot was initially issued a Private Pilot Licence (PPL) on 27 December 1993 with the aircraft type endorsed on it. His last PPL re-validation was on 9 June 2020 with an expiry date of 30 June 2021. The pilot had a total of 721.2 flight hours and 80.5 of those hours were on the aircraft type. The co-pilot had a Class 2 aviation medical certificate on 4 June 2020 with an expiry date of 30 June 2021.

This was a private flight conducted in terms of Part 91 of the CAR 2011 as amended.

B. Weight and Balance

2.2.2 The weight and balance calculation on this report was based on the information supplied by the pilot. According to available information, the aircraft's certified maximum take-off weight is 3600 pounds (lbs). On the day of the accident, the aircraft's weight was approximately 3281.2lbs, which is below the maximum certificated take-off weight.

C. Machine

2.2.3 The accident aircraft was registered to the current owner on 1 August 2019. Engine serial no L-5536-61A was installed on ZS-CKM in 2016. The last engine overhaul was carried out by CRS # RF4R490M in the United States of America on 20 January 2000 at 2 924 engine total hours. The engine was test-run for 2 hours and preserved for short-time storage; it was later shipped to South Africa. According to available information, a gear tooth was found during an MPI on 1 June 2018 and at 3 979.5 total hours. The engine was stripped and inspected for damage on all the gears, and they were found serviceable. The origin of the gear tooth could not be found, and the engine was reassembled and refitted to the aircraft.

2.2.4 During the accident flight, the PIC stated that a minute or two before top of descent, they heard a loud noise coming from the engine, as well as noticed severe vibration and a reduction in engine power. The crew immediately set course for the nearest airport, which was FAMG whilst they carried out fault-finding procedures to rectify the problem; however, the exercise produced no positive results. The engine lost power before it finally stopped. Following the accident, the engine was removed from the aircraft and was sent to an approved engine workshop for inspection. The engine strip was carried out and, on inspection, it was found that the engine crankshaft had broken at two points. The broken crankshaft was sent for metallurgical inspection.

2.2.5 Investigation results of the supplied components revealed two primary fractures, A and B (see photo 6), which initiated and progressed due to predominant fatigue in the web sections of the crankshaft during operation. A qualitative Non-destructive Testing (NDT) Dye-Penetrant Inspection (DPI) revealed extensive micro-fracture initiations around the main bearing (M3) contact surface circumference at fracture position B (Photo 10, red circle). This is indicative of severe stress exposure to the crankshaft in the radial direction during rotation and not related to a typical bearing failure (seizure, break-up, etc.). According to the manufacturer, engine overhaul should be carried out at every 2000 hours or 12-year mark. The crankshaft should be inspected for condition and wear limits and measured to determine if it is still within limits. The crankshaft that is out of limits should be replaced.

2.2.6 It is likely that the engine, which had been operating for more than 21 years without adhering to the manufacturer's recommended overhaul procedures and ADs, had an existing crack which was identified through metallurgical testing post-accident. This indicated that the crankshaft was not put through NDT DPI which would have identified the crack, and thus, the replacement of the crankshaft recommended. According to available information, the engine was subjected to frequent "blow-bys" and borescope inspections as recommended by the SACAA's AIC 18.19; however, these inspections could not detect the crack that had developed over time, and which resulted in the failure of the crankshaft.
The investigation revealed that the ZS-CKM's crankshaft failure was attributed to fatigue cracking associated with operational stresses. This is supported by ATSB research and analysis on the failure of Lycoming engines.

3. CONCLUSION

3.1. General

From the available evidence, the following findings, causes and contributing factors were made with respect to this accident. These shall not be read as apportioning blame or liability to any particular organisation or individual.

To serve the objective of this investigation, the following sections are included in the conclusion heading:

- **Findings —** are statements of all significant conditions, events or circumstances in this accident. The findings are significant steps in this accident sequence, but they are not always causal or indicate deficiencies.
- **Causes —** are actions, omissions, events, conditions or a combination thereof, which led to this accident.
- **Contributing factors —** are actions, omissions, events, conditions or a combination thereof, which, if eliminated, avoided or absent, would have reduced the probability of the accident occurring, or would have mitigated the severity of the consequences of the accident. The identification of contributing factors does not imply the assignment of fault or the determination of administrative, civil or criminal liability.

3.2. Findings

3.2.1 The PIC was initially issued an Airline Transport Pilot Licence (ATPL) on 6 June 2019. His last licence validation was on 9 June 2020 with an expiry date of 30 June 2021.

3.2.2 The PIC was issued a Class 1 aviation medical certificate on 26 November 2020 with an expiry date of 30 November 2021.

3.2.3 The co-pilot was initially issued a Private Pilot Licence (PPL) on 27 December 1993. His last licence validation was on 9 June 2020 with an expiry date of 30 June 2021.

3.2.4 The co-pilot was issued a Class 2 aviation medical certificate on 4 June 2020 with an expiry date of 30 June 2021.

3.2.5 The aircraft was initially issued a Certificate of Airworthiness (CoA) on 24 April 2016 with an expiry date of 30 April 2022. The aircraft's Certificate of Registration was issued to the current owner on 1 August 2019.

3.2.6 The aircraft was issued a Certificate of Release to Service on 15 October 2020 with an expiry date of 15 October 2021 or at 4 130.71 airframe hours, whichever occurs first.

3.2.7 The last 100-hour/1-year MPI was carried out on 16 October 2020 at 4 034.73 airframe hours. The aircraft had accumulated an additional 72.05 airframe hours in operation since the last maintenance inspection.

3.2.8 The flight, which was privately operated, was conducted under the provisions of Part 91 of the Civil Aviation Regulations (CAR) 2011 as amended.

3.2.9 The AMO that carried out the last maintenance inspection prior to the accident flight was in possession of an AMO-approval certificate issued on 1 December 2020 with an expiry date of 30 November 2021.

3.2.10 The aircraft's engine lost power and finally stopped. The engine's loss of power and stoppage was caused by the failure of the camshaft. The crew identified a small road in Umtentweni on which they executed a forced landing.

3.2.11 According to the PIC, the aircraft was last refuelled with 92 US gallons of Avgas on 13 May 2021.

3.2.12 The crankshaft was not inspected for condition and wear limits at 2000 hours or 12-year mark as per the manufacturer's recommendation. The aircraft's crankshaft failure was attributed to fatigue cracking associated with operational stresses.

3.3. Probable Cause

3.3.1 The crankshaft broke at two points during flight due to fatigue, which resulted in engine stoppage and the subsequent unsuccessful forced landing on the gravel road.

3.4 Contributing factor:

3.4.1 The crankshaft was not inspected for wear and condition at every 2000 hours or 12-year mark as per the manufacturer's recommendation.

4. SAFETY RECOMMENDATIONS

4.1. General

The safety recommendations listed in this report are proposed according to paragraph 6.8 of Annex 13 to the Convention on International Civil Aviation and are based on the conclusions listed in heading 3 of this report. The AIID expects that all safety issues identified by the investigation are addressed by the receiving States and organisations.

4.2. Safety Recommendation/s

4.2.1 According to the engine manufacturer, engine overhaul should be carried out at every 2000 hours or 12-year mark. During overhaul, the crankshaft should be inspected for condition and wear, and measured to determine if it is still within limits. All the wear limits are stated in the overhaul manual. A crankshaft that is out of limits should be replaced.
However, the South African Civil Aviation Authority has issued an Aeronautical Information Circular (AIC) 18.19 which supersedes the manufacturer's maintenance schedule.

It is recommended to the Director of Civil Aviation to review or cancel the AIC, which states that private operators (need) not comply with the manufacturer's calendar requirements for engine overhaul. The review should determine if the AIC 18.19 is still relevant considering the revised manufacturer's mandatory Service Bulletin (SB) for engine overhauls.

4.2.2 An Airworthiness Directive (AD) 2002-19-03 (effective September 20, 2002) was sent previously to all known U.S. owners and operators of Textron Lycoming LTIO-540 and TIO-540 series engines rated at 300 horsepower (HP) or higher. The AD requires that before the next flight is undertaken, certain serial numbered crankshafts that were hammer-forged be replaced with the crankshafts that were press-forged. This AD was prompted by reports of crankshaft failures in LTIO-540 and TIO540 engines, rated at 300 HP or higher. Investigation of the engine logbook revealed that this AD was not applicable to this crankshaft by part and/or serial number, therefore, it is recommended that the manufacturer expands the AD 2002-19-03 to include all crankshaft and piston engine serial numbers.

5. APPENDICES

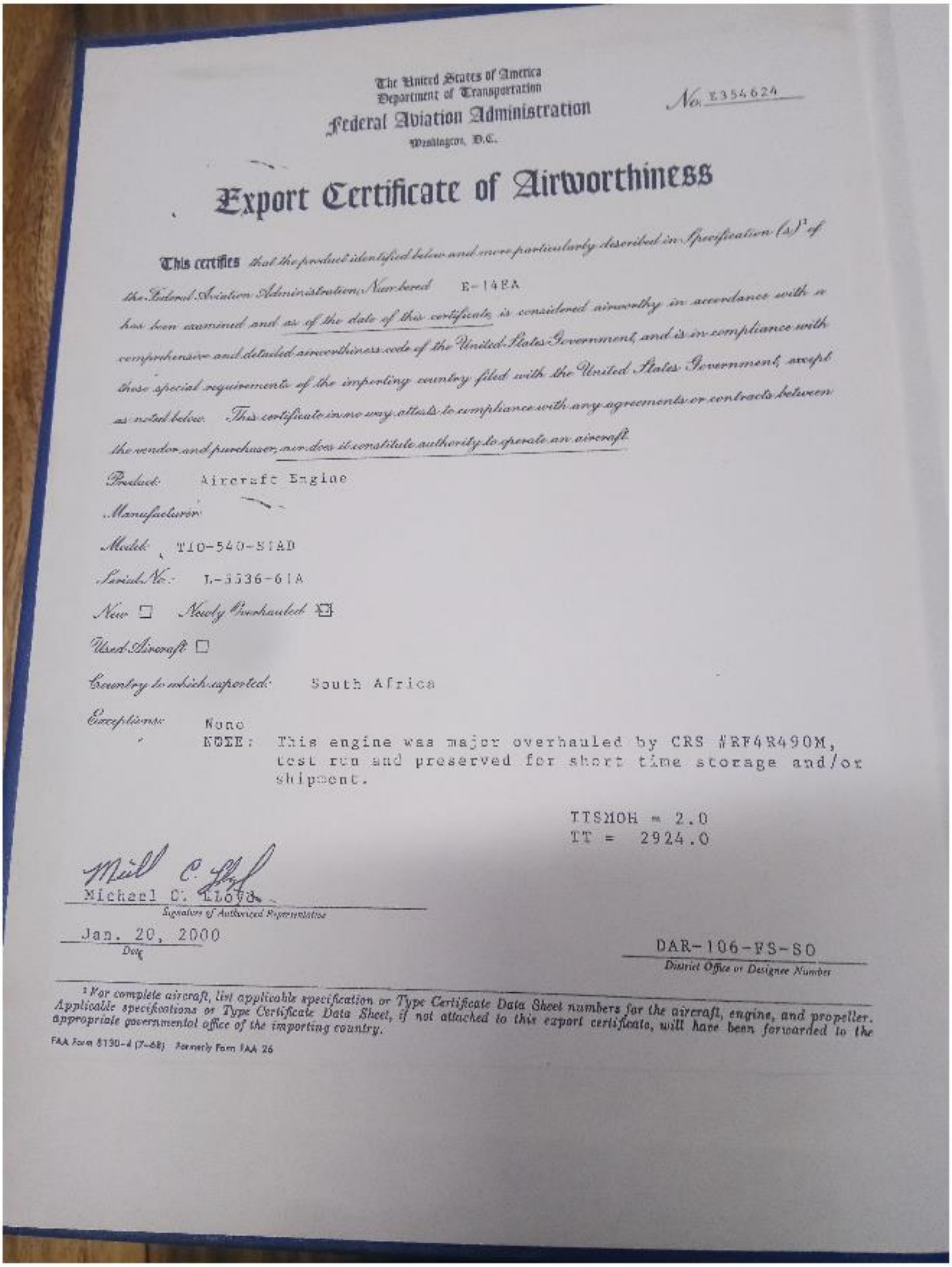
5.1 Annexure A: Engine Export Certificate of Airworthiness.

5.2 Annexure B: Failure Analysis Report – Crankshaft Assembly, Lycoming TIO-540-S1AD

This report is issued by:

Accident and Incident Investigations Division
South African Civil Aviation Authority
Republic of South Africa

Annexure A



The United States of America
Department of Transportation
Federal Aviation Administration
Washington, D.C.

No. E354624

Export Certificate of Airworthiness

This certifies that the product identified below and more particularly described in Specification (s)[1] of the Federal Aviation Administration, Numbered E-14EA has been examined and as of the date of this certificate is considered airworthy in accordance with a comprehensive and detailed airworthiness code of the United States Government, and is in compliance with those special requirements of the importing country filed with the United States Government, except as noted below. This certificate in no way attests to compliance with any agreements or contracts between the vendor and purchaser, nor does it constitute authority to operate an aircraft.

Product: Aircraft Engine

Manufacturer:

Model: TIO-540-S1AD

Serial No.: L-3536-61A

New ☐ Newly Overhauled ☒

Used Aircraft ☐

Country to which exported: South Africa

Exceptions: None

NOTE: This engine was major overhauled by CRS #RF4R490M, test run and preserved for short time storage and/or shipment.

TTSMOH = 2.0
TT = 2924.0

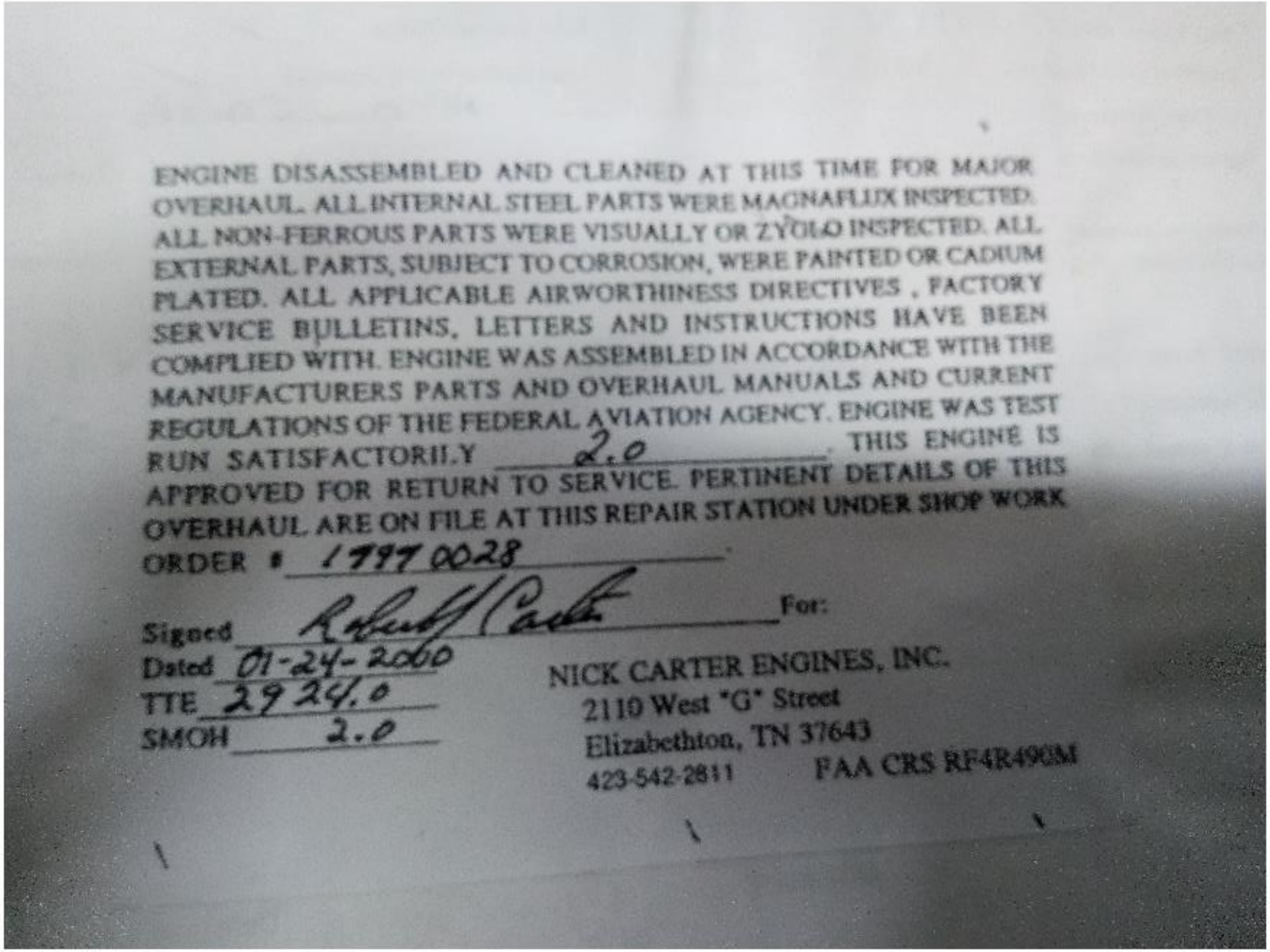
Michael C. Lloyd
Signature of Authorized Representative

Jan. 20, 2000
Date

DAR-106-FS-SO
District Office or Designee Number

[1] For complete aircraft, list applicable specification or Type Certificate Data Sheet numbers for the aircraft, engine, and propeller. Applicable specifications or Type Certificate Data Sheet, if not attached to this export certificate, will have been forwarded to the appropriate governmental office of the importing country.

FAA Form 8130-4 (7-68) Formerly Form FAA 26



ENGINE DISASSEMBLED AND CLEANED AT THIS TIME FOR MAJOR OVERHAUL. ALL INTERNAL STEEL PARTS WERE MAGNAFLUX INSPECTED. ALL NON-FERROUS PARTS WERE VISUALLY OR ZYGLO INSPECTED. ALL EXTERNAL PARTS, SUBJECT TO CORROSION, WERE PAINTED OR CADIUM PLATED. ALL APPLICABLE AIRWORTHINESS DIRECTIVES , FACTORY SERVICE BULLETINS, LETTERS AND INSTRUCTIONS HAVE BEEN COMPLIED WITH. ENGINE WAS ASSEMBLED IN ACCORDANCE WITH THE MANUFACTURERS PARTS AND OVERHAUL MANUALS AND CURRENT REGULATIONS OF THE FEDERAL AVIATION AGENCY. ENGINE WAS TEST RUN SATISFACTORILY 2.0. THIS ENGINE IS APPROVED FOR RETURN TO SERVICE. PERTINENT DETAILS OF THIS OVERHAUL ARE ON FILE AT THIS REPAIR STATION UNDER SHOP WORK ORDER # 1997 0028.

Signed [signature] For:

Dated 01-24-2000

TTE 2924.0

SMOH 2.0

NICK CARTER ENGINES, INC.
2110 West "G" Street
Elizabethton, TN 37643
423-542-2811 FAA CRS RF4R490M

Annexure B

COMPILED BY:	LABORATORY FOR MICROSCOPY & MICROANALYSIS	PAGE 1 OF 12
	FAILURE ANALYSIS REPORT: Crankshaft Assembly, Lycoming TIO-540-S1AD, Piper Turbo Lance II, ZS-CKM	DOCUMENT NUMBER FA-007-06-21
COMPILED FOR: AAS		DATE 2021-06-12 / ISSUE 1

ITEM: **Crankshaft assembly, Lycoming TIO-540-S1AD engine, Piper Turbo Lance II PA-32-RT-300T, ZS-CKM**

1. BACKGROUND INFORMATION

1.1. The fractured Crankshaft Assembly (Photo 3), serial number LW15302, from a Lycoming TIO-540-S1AD reciprocal engine, serial no L-5536-61A, originating from a Piper PA-32-RT-300T Turbo Lance II, aircraft no ZS-CKM (Photo 1), was submitted to determine the most probable modes of failure and possible contributing factor/s.

1.2. The aircraft was involved in an in-flight engine failure resulting in a non-fatal accident (Photo 2).

1.3. Supplied information[1] relating to the service history of the relevant engine, serial no L-5536-61A, revealed the following important events:

1.3.1. 19/09/2019: Engine was removed following after the operator reported it 'difficult to turn' at Hobbs time: 1513.40h. According to unverified supplied information, the engine crankcase was replaced at this time by the AMO due to a possible dislocation of a main bearing(s) during operation. The relevant crankshaft assembly were not removed or disassembled.

1.3.2. 06/06/2020: The engine was removed and forwarded to the same AMO to replace the crank oil seal due to leaking at Hobbs time: 1542.14h. The relevant crankshaft assembly were not removed or disassembled.

1.34.3. 13/05/2021: Engine failure during operation at Hobbs time: 1624.50h.

Photo 1: Piper Turbo Lance II, ZS-CKM[2]

Photo 2: Accident Site, ZS-CKM[3]

[1] Courtesy AAS, TAM, Owner
[2] Courtesy Jetphotos
[3] Courtesy Owner

CRANKSHAFT ASSEMBLY, PIPER TURBO LANCE II, ZS-CKM ©Laboratory for Microscopy and Microanalysis

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	FAILURE ANALYSIS REPORT: Crankshaft Assembly, Lycoming TIO-540-S1AD, Piper Turbo Lance II, ZS-CKM	DOCUMENT NUMBER FA-007-06-21
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Photo 3: Supplied assembly (Digital)

1.2. This report is divided into the following sections:

2. APPLICABLE DOCUMENTS

(a) Lycoming Engine Parts catalogue PC-315-4.
(b) Supplied information – Flight Folios release certificates, etc.

3. DEFINITIONS

(a) OEM Original Equipment Manufacturer
(b) SEM Scanning Electron-microscope
(c) NDT Non-Destructive Testing
(d) IPC Illustrated Parts Catalogue
(e) EDS Energy Dispersive X-ray Spectroscopy

4. PERSONNEL

(a) The investigative member and compiler of this report is a qualified Physical Metallurgist (H.N.Dip. Metallurgical Engineering, Tech. PTA, ECSA Registration: Prof. Eng. Tech. No 201670194), Radiation Protection Officer (RPO, NNR, No 281) and Aircraft Accident Investigator (SCSI).

5. APPARATUS AND METHODOLOGY

(a) The methodology included visual inspection, sectioning and preparing samples for Light-, Stereo-, EDS and Electron-microscopy.

6. INVESTIGATION RESULTS

6.1. Inspection Results

6.1.1. On-site Inspection

The engine was inspected at AEP, Wonderboom-Airport, after partial tear down. The crankcase revealed severe damages attributable to the fractured crankshaft during operation.

The oil pump revealed no clear signs of failure during operation (Photo 4).

The main sleeve bearings (Diagram 2) revealed signs of wear, metal impregnation and temperature exposures (Photo 5).

Photo 4: Oil pump condition[4]

Photo 5: Main bearing condition (Digital)

[4] Courtesy AAS

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	FAILURE ANALYSIS REPORT: Crankshaft Assembly, Lycoming TIO-540-S1AD, Piper Turbo Lance II, ZS-CKM	DOCUMENT NUMBER FA-007-06-21	
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6.1.2. Laboratory Inspection

Visual inspection of the supplied crankshaft revealed two fractures marked A and B (Photo's 7 and 8) within the web sections between the adjacent main bearings M2 and M3 and piston conrod positions 3 and 4 (Photo 6; Diagrams 1 and 3). Both fracture surfaces revealed signs corresponding with a fatigue mode of failure and initiated within the radius sections of the main bearings M2 and M3 respectively (Photo's 7 and 8, red circles). The fractures progressed through the web sections in the directions as indicated (yellow arrows) until final fast fracture.

The 'beachmark' spacing, level of secondary damage and surface contamination indications suggest that fracture A initiated prior, or progressed at a higher rate, than fracture B.

Both the main bearing contact surfaces M2 and M3 (Photo's 7 and 8, yellow arrows) revealed slight signs of wear and temperature exposure. This is not consistent with a total bearing seizure scenario and can be considered as collateral damages induced during the crankshaft failure sequence.

A qualitative NDT Dye-Penetrant Inspection (DPI) revealed extensive micro-fracture initiations around the main bearing (M3) contact surface circumference at fracture position B (Photo 10, yellow dashed circle). This is indicative of severe stress exposure to the crankshaft in the radial direction during rotation and not related to a typical bearing failure (seizure, break-up, etc.).

The big-end connecting rods C1 and C2 (Diagram 1; Photo 6) and bearings revealed signs of high temperature exposures, excessive wear and imminent seizure (Photo 9). This could be considered as collateral damages induced during the failure sequence of the crankshaft due to the blockage of the oil feed lines.

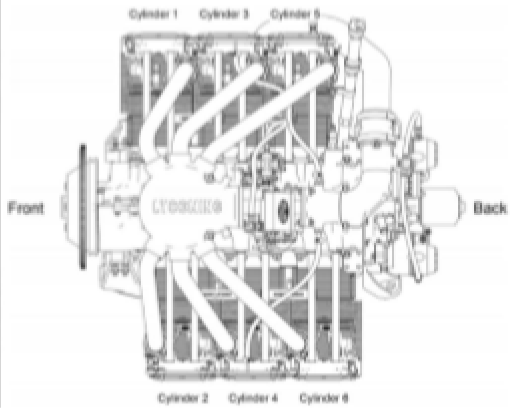

Diagram 1: Engine layout

CRANKSHAFT ASSEMBLY, PIPER TURBO LANCE II, ZS-CKM

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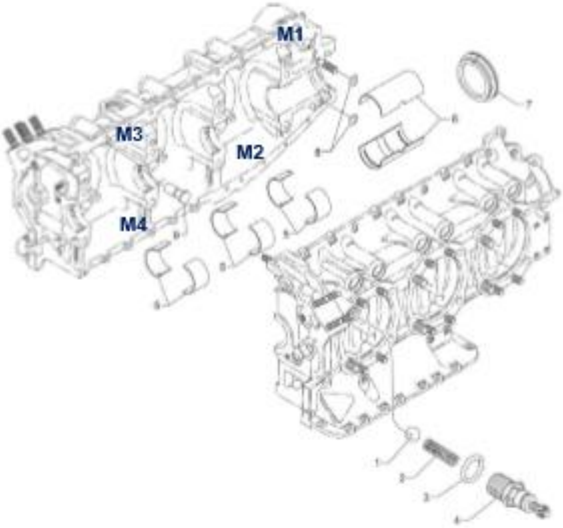

Diagram 2: Main bearings- and crankcase layout

CRANKSHAFT ASSEMBLY, PIPER TURBO LANCE II, ZS-CKM

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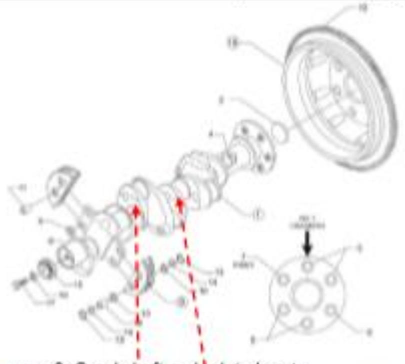


Diagram 3: Crankshaft and related parts

Photo 6: Position of primary fractures A and B and other parts (Digital)

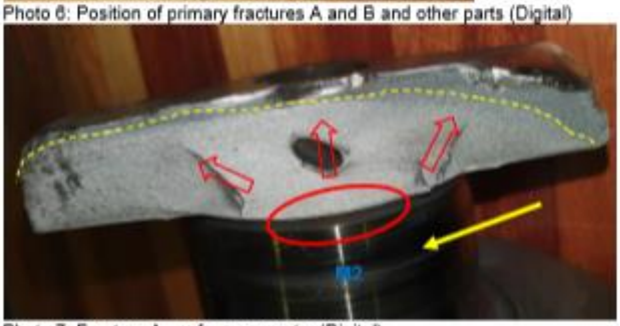


Photo 7: Fracture A, surface geometry (Digital)

CRANKSHAFT ASSEMBLY, PIPER TURBO LANCE II, ZS-CKM ©Laboratory for Microscopy and Microanalysis

Photo 8: Fracture B, surface geometry (Digital)

Photo 9: Connecting rod C1 condition (Digital)

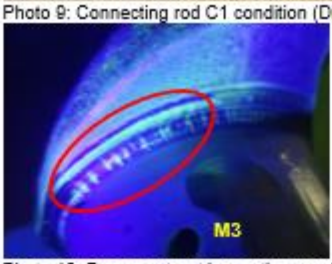


Photo 10: Dye-penetrant inspection result (Digital)

6.1.3. Microscopy

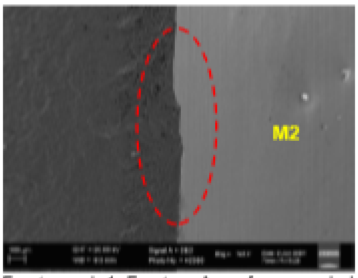
Fracture initiations (Fractograph 1, red dashed circle) at both fractures A and B proved to be preferential to the original machining marks. In the absence of evidence towards prior overhaul procedure/s involving machining at these positions, this supports the notion towards an applied radial stress during operation resulting in surface fracture initiation (Photo 10). When one, or more, of these surface fractures reach a critical flaw size (a function of material condition and applied stress parameters) the fracture will progress under a fatigue mode of failure till final fast failure.

The fracture surface analysis at **Fracture A** revealed clear signs of fatigue 'beachmarks' (Fractograph 2, yellow dashed lines) with a clear progression direction (red arrows). Foreign deposits at the initiation zone (Fractograph 2, blue dashed circle) confirms the existence of the fracture for an undetermined period of engine operation. At higher magnifications the surface morphology revealed fatigue striations (Fractograph 3) confirming the predominant failure mode (high frequency, low stress). The final fast fracture zone revealed a typical microvoid-coalescence morphology (Fractograph 4) consistent with an overload condition.

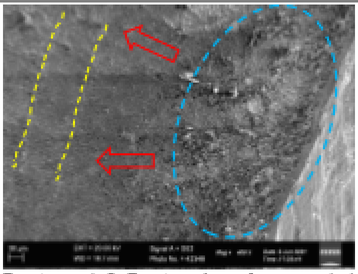
The fracture surface analysis at **Fracture B** revealed multiple initiation positions (Fractographs 5 and 6) and planes. Selective initiation points correspond with the noted micro-fractures (Fractographs 6, 7 and 8, green arrows; Photo 10, red circle). Clear signs of typical fatigue 'beachmarks' (Fractograph 5, yellow dashed lines) and progression directions were noted (red arrows). The absence of clear striations within the morphology at higher magnifications suggest that Fracture B progressed under repeated overload conditions (low-frequency, high stress) supporting the notion that Fracture A initiated first in the sequence and/or progressed at a higher rate.

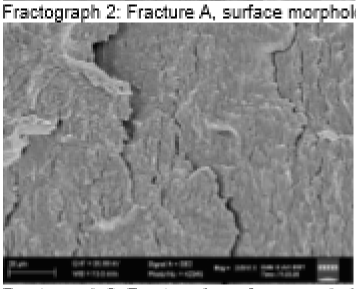
Smearing damages surrounding the micro-fractures (Fractograph 8, red dashed circle) support the notion that these fractures were exposed to an operating environment for an undetermined period.

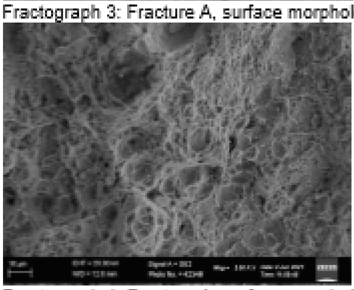
The EDS MAP results confirmed the presence of lead (Pb) impregnated onto the fracture surfaces (EDS MAP Result 1). Lead originates from the sleeve bearing material and supports the notion that the fractures were exposed to the operating environment for an undetermined period.

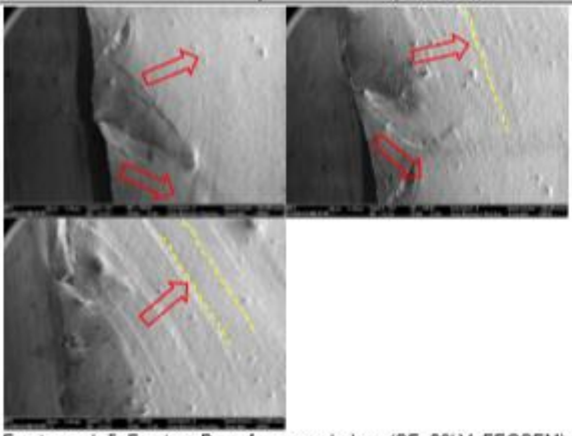


Fractograph 1: Fracture A, surface morphology (145X, SE, 20kV, FEGSEM)

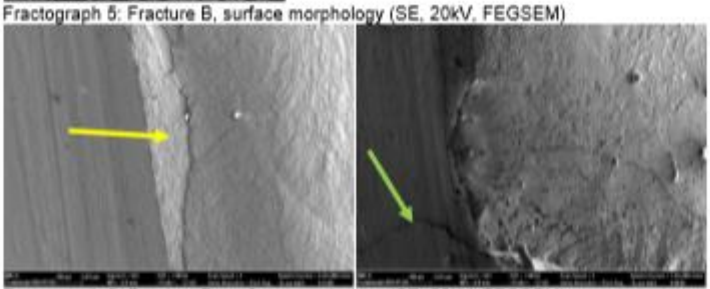

Fractograph 2: Fracture A, surface morphology (400X, SE, 20kV, FEGSEM)


Fractograph 3: Fracture A, surface morphology (3000X, SE, 20kV, FEGSEM)

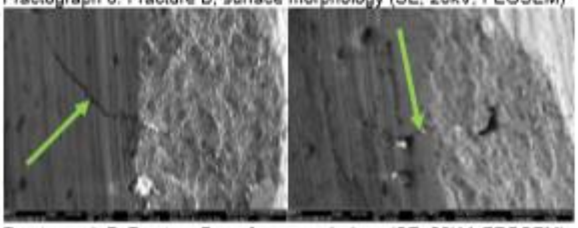

Fractograph 4: Fracture A, surface morphology (2000X, SE, 20kV, FEGSEM)



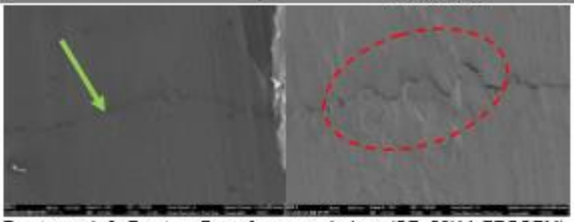
Fractograph 5: Fracture B, surface morphology (SE, 20kV, FEGSEM)



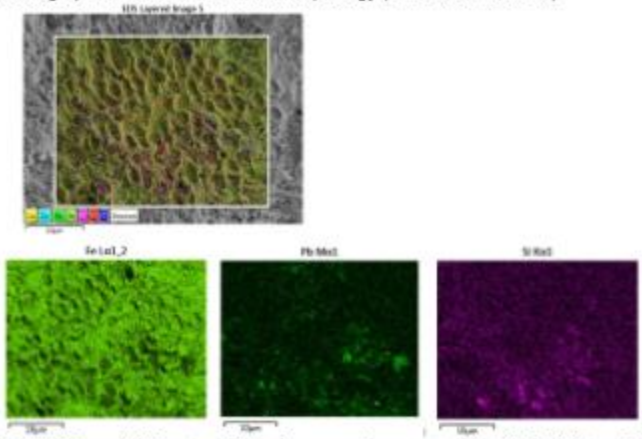
Fractograph 6: Fracture B, surface morphology (SE, 20kV, FEGSEM)



Fractograph 7: Fracture B, surface morphology (SE, 20kV, FEGSEM)



Fractograph 8: Fracture B, surface morphology (SE, 20kV, FEGSEM)



EDS MAP result 1: Fracture B, Surface smearing composition (Oxford Aztec, 20kV, SE)

7. DISCUSSION AND CONCLUSIONS

<u>Note 1</u>: *The conclusions are based on the investigation results obtained from the supplied parts/components and information only. All information supplied to this investigation from other parties are considered factual.*

7.1. The investigation revealed <u>two primary fractures</u>, A and B, initiated and progressed with predominant fatigue mode features within the web sections of the crankshaft during operation.

7.2. Secondary, <u>micro-fractures</u> were noted adjacent to the primary fracture positions. These micro-fractures in turn induced multiple fatigue fracture initiations. The most probable cause towards the formation of these micro-fractures could be the incident at Hobbs time 1513.40h (ref. p.1.3.1). Dislocation of a main bearing would require <u>dimensional changes</u> brought about by one or more of the following: loss of crankcase bolt torque, excessive sleeve bearing wear, collapse of the crankcase bearing journal or incorrect fitment. *None of the aforementioned were* *confirmed by this investigation*. However, this dimensional change at the main bearing position/s will inevitably influence the applied load conditions on the rotating crankshaft during operation. This will allow for a variable radial stress exposure over the length of the crankshaft, but most prominent at the centre section where the primary fractures initiated.

7.3. The fracture surface analysis results suggest that Fracture A initiated prior, or progressed at a higher rate, than Fracture B. The most probable sequence is that micro-fractures initiated within the radius sections of both A and B and on reaching the critical flaw size, A progressed first/faster allowing for increased crankshaft radial movement that in turn influenced and increased the progression rate at B.

7.4. Foreign deposits originating from the sleeve bearing material and operating environment confirms the existence of both the primary fractures A and B for an undetermined period.

8. RECOMMENDATIONS

8.1. None applicable.

9. DECLARATION

9.1. All digital images have been acquired by the author, unless otherwise stated, and displayed in an un-tampered manner.