Air Accident Investigation Unit Ireland

SYNOPTIC REPORT

ACCIDENT
Cessna TU206G Stationair 6, G-SKYE
Near Abbeyshrule, Co. Longford
21 June 2014

An Roinn Iompair
Turasóireachta agus Spóirt
Department of Transport,
Tourism and Sport

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 460 of 2009, the Chief Inspector of Air Accidents, on 21 June 2014, appointed Mr John Owens as the Investigator-in-Charge to carry out an Investigation into this Accident and prepare a Report.

Aircraft Type and Registration:	**Cessna TU206G Stationair 6, G-SKYE**
Number and Type of Engines:	**1 x Continental TSIO-520-M**
Aircraft Serial Number:	**U206-04568**
Year of Manufacture:	**1978**
Date / Time (UTC):[4]	**21 June 2014 @ 11.10 hrs**
Location:	**1.6 Nautical miles (nm) west northwest (WNW) of Abbeyshrule airfield (EIAB)**
Type of Operation:	**Aerial Work (Parachute Operations)**
Persons on Board:	**Pilot - 1 Other - 4**
Injuries:	**Pilot - None Other - 4 (Minor)**
Nature of Damage:	**Substantial**
Commander's Licence:	**CPL (A)[5] issued by the Irish Aviation Authority (IAA)**
Commander's Details:	**Male, aged 53 years**
Commander's Flying Experience:	**870 hours of which 116 were on type**
Notification Source:	**Aircraft Engineer at EIAB**
Information Source:	**AAIU Report Form submitted by Pilot, AAIU Field Investigation**

[4] **UTC**: Co-ordinated Universal Time. All times in this report are UTC (local time minus one hour on the accident date).
[5] **CPL (A):** Commercial Pilot Licence (Aeroplane).

SYNOPSIS

The aircraft, a Cessna TU206G, was being used for parachuting/skydiving activities at Abbeyshrule (EIAB) on the day of the accident. Shortly after take-off, the Pilot felt what was described as a “*knock*” following which the engine lost power. This resulted in the Pilot making a forced landing in a nearby field. There were five people on board the aircraft - the Pilot and four skydivers. The skydivers comprised of two tandem pairs, with each pair being made up of a qualified skydiver and a person skydiving for charity secured to him. Following the forced landing, all occupants successfully evacuated the aircraft, which sustained substantial damage. The Pilot and qualified skydivers reported no injuries at the scene. The two charity skydivers attended a local hospital, but were released a short time later. The Investigation found that the cause of the engine power loss was a failure of the crankshaft.

NOTIFICATION

An Aircraft Engineer based near EIAB advised the AAIU of the accident at 11.33 hrs. Two AAIU Investigators travelled to the scene and arrived there at approximately 14.00 hrs to commence the Investigation.

1. FACTUAL INFORMATION

1.1 Tandem Skydive Operations

Tandem skydiving refers to a type of skydiving where a student or other person is secured to a qualified skydiver known as a tandem master. When the aircraft reaches the planned altitude and position, the tandem master with the other person attached to him/her, exits the aircraft. The tandem master controls the jump from aircraft exit, through free-fall, parachute deployment and landing.

1.2 History of the Flight

The Pilot who flew the aircraft on the accident flight refuelled it before performing the first three flights of the day. Another pilot then flew the aircraft for the next three flights, after which it was refuelled again. The Pilot who had flown the first three flights then took the aircraft for its seventh flight that day.

The aircraft took off from Runway (RWY) 28 at EIAB at approximately 11.09 hrs. In addition to the Pilot, there were four persons on board - two Tandem Masters, and two other occupants, each of whom was secured to a Tandem Master for the purpose of tandem skydiving. The Pilot reported that the take-off roll was normal but that during the initial climb, he felt a “*knock*” and then noticed that the engine was running “*rough*”. He said that he levelled the aircraft at 400 feet (ft) and checked the engine oil pressure and fuel flow and found these to be okay. He reported that the fuel mixture was set to “*rich*” and that he switched on the fuel boost pump but that the engine continued to run “*rough*” and was “*getting worse*”. Because of this, he decided to carry out a forced landing.

He made a 'Pan'[6] call to EIAB and selected a field to his right in which to land. He commented that at this stage the "*engine note*" was "*up and down*" and he was losing altitude but he didn't shut the engine down as he thought that it may have been providing some power. He realised that he was not going to make the chosen field and noticed another field to his left. He made a turn to the left, but then saw livestock in the upper right hand corner of the field. The Pilot reported that he adjusted the aircraft's approach path accordingly and picked his landing spot. He said that he was aware of trees on the approach, but knew he could clear them. He flared the aircraft and felt it sink for "*maybe six feet*", before it made contact with the surface of the field and bounced. When the aircraft contacted the ground for the second time, the nose landing gear collapsed, however the aircraft continued in a straight line. The left hand wing tip then contacted the ground following which the aircraft returned to wings level and came to rest a short distance later (**Photo No. 1**).

The Pilot reported that he pulled the mixture control and moved the fuel selector to OFF. He turned off all switches and instructed the occupants to evacuate and move away from the aircraft. Having ascertained that everyone was okay, he phoned the controller at EIAB and explained what had happened. Emergency personnel arrived shortly thereafter.

Photo No. 1: Final resting position of G-SKYE, with nose 'dug-in' and damage to left hand wing.

1.3 Landing Site

The field where the forced landing was made was 1.6 nm WNW of EIAB. The ground was gently sloping downhill away from the direction of landing. Although the grass-covered surface was cattle-trodden, it was firm and except for trees on the approach and the perimeter hedging, it was obstruction free.

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[6] **PAN:** A state of urgency is declared to Air Traffic Control by speaking the words "Pan-Pan" three times.

A survey of the site conducted by the Investigation indicated that the initial point of contact was 56 metres (m) from the eastern edge of the field. The aircraft then travelled along the ground for about 10 m in a westerly direction before becoming airborne again for approximately 14 m. Shortly after the aircraft touched down again, the nose landing gear collapsed. The aircraft continued in a straight line for a further 35 m before the left hand wing tip briefly contacted the ground. This caused the aircraft to turn to the left slightly. The aircraft returned to wings level and came to rest a short distance later, approximately 112 m from the eastern edge of the field on a heading of 270^{o} magnetic.

1.4 Injuries

No injuries were reported at the scene. The Investigation was informed that both persons who were jumping for charity attended a local hospital that afternoon but were released later that day. Subsequently, one of the charity jumpers reported attending a hospital approximately one week later due to neck pain, and was also not detained. The other charity jumper, when interviewed approximately two weeks after the accident, said that a week after the accident his neck was a bit sore but was okay now. Two days after the accident, one of the Tandem Masters attended a hospital with a possible shoulder injury. He was informed that he had a soft tissue injury and was not detained. The other Tandem Master later reported that he received a bruise to his head when he contacted the extended right hand control wheel/column during the forced landing. None of the occupants was wearing a helmet.

1.5 Damage to Aircraft

The aircraft was substantially damaged as a result of the accident. When the aircraft touched down following the bounce, the nose landing gear collapsed, which resulted in damage to the nose area of the aircraft. Two of the three propeller blades were bent and the engine bulkhead was distorted. Some damage was also sustained to the lower fuselage skin. The left wing tip was damaged when it contacted the ground, which resulted in damage to the upper fuselage between the wings.

When the nose of the aircraft was lifted at the accident site, it was identified that the propeller, and hence the engine, could be turned with ease for approximately 20^{o} before becoming more difficult to turn. On preliminary examination of the piston movement with the spark plugs removed, it was suspected that the crankshaft was broken aft of cylinders five and six (the front two cylinders), **Section 1.12** refers.

1.6 Other Damage

There was localised damage to the surface of the field where the forced landing was made.

1.7 Personnel Information

The Pilot held a CPL (A) with a Single Engine Piston (SEP) rating. This licence was issued by the IAA and was valid until 8 June 2016. The Pilot also held a Class 1 medical certificate for single-pilot, commercial air transport passenger-carrying operations which was valid until 14 April 2015. The Pilot's operating experience is listed in **Table No.1**.

Total all types P1:	870 hours
Total on type:	116 hours
Last 90 days:	12 hours
Last 28 days:	7 hours (all on type)
Last 24 hours:	1.5 hours (all on type)

Table No. 1: Operating experience of Pilot.

1.8 Interviews

1.8.1 Pilot Interview

The Pilot was interviewed at the accident site. He said that he conducted standard run up checks prior to take-off and that during the take-off, the manifold pressure[7] and engine RPM[8] were normal. The Pilot said that after take-off, he selected the flaps to UP, throttled back the engine to 29 inches (manifold pressure) and set the propeller speed to 2,450 RPM for the climb. He said that at about 400 ft, he felt that something was not right - that the engine was running "*a bit rough and as if fuel was not getting through*". He said that the aircraft could not sustain flight, so he committed to making a forced landing.

1.8.2 Tandem Masters

Both Tandem Masters were interviewed. One of the Tandem Masters, who was an experienced parachutist with over 7,000 jumps, was sitting at the front of the aircraft cabin on the floor in a rearward facing position. He realised after take-off that there was a problem with the aircraft's engine and that the Pilot was going to have to land in a field. The Tandem Master said that he advised the charity jumpers of the situation. He also stated that just before the forced landing, he realised that the Pilot was going to need to flare the aircraft and that because of where he (the Tandem Master) was seated, his head would obstruct the full aft movement of the right hand control column/wheel. Because of this, he slid down lower to ensure that the Pilot "*was able to flare all the way back without my head restricting him*". The Tandem Master said that if the control column/wheel had hit his head during the landing, "*we wouldn't have got the full flare and might have hit harder*". He advised that when the aircraft landed he "*bounced a little bit up and hit the* [extended] *column*", receiving a bruise to his head.

1.9 Meteorological Information

Met Éireann was asked to provide details on the weather conditions at EIAB on the day of the accident. They stated that the meteorological conditions were as follows: Wind 5 knots (kts) between 330^{o} and 360^{o}, clouds '*few*' at 2,500 ft, '*broken*' at 4,200 ft, surface temperature 18^{o} to 19^{o} Centigrade (C), Mean Sea Level Pressure 1023 hPa[9], visibility 35 km.

[7] **Manifold pressure:** An indication of engine power, usually displayed in inches of mercury.
[8] **RPM:** Revolutions per minute (engine rotational speed).
[9] **hPa:** Hectopascal – A unit of pressure.

1.10 Aircraft Information

1.10.1 General

The aircraft, a Cessna TU206G Stationair 6, registration G-SKYE, was manufactured in 1978 and was fitted with a Continental TSIO-520-M (7) engine. It was owned and registered in the United Kingdom (UK) and was normally based there, but had been leased on 30 May 2014 by a skydiving club operating in Ireland. The aircraft had a maximum take-off weight of 1,633 kgs (3,600 lbs.). The cockpit had seating on the left hand side for one pilot which was fitted with a restraint harness. To facilitate parachute operations, there was no right hand cockpit seat installed. The rudder pedals and foot well area on the right hand side of the cockpit were blocked off with a wooden structure. The right hand control column/wheel remained in-situ and was not blocked off (**Photo No. 2**).

Photo No. 2: Cockpit of G-SKYE showing wooden structure at right hand foot well area.

At the time of the accident, the aircraft had flown for a total time of 4,196 hours. The associated log books indicated that it operated for approximately 98 hours since 24 June 2009. From this date until the date of the accident, the aircraft did not operate during the periods indicated in **Table No. 2.** It operated for approximately six hours in 2013 and for approximately 20 hours in 2014.

Aircraft Not Operational From:	To:	No. of Days
9 August 2009	15 April 2010	249
25 September 2010	16 May 2011	233
11 September 2011	4 June 2012	267
9 September 2012	7 November 2013	424
22 November 2013	4 May 2014	163

Table No. 2: Periods when aircraft was not in operation.

The Supplements section of the Pilot's Operating Handbook (POH) for the aircraft contained *'Supplement 3, Issue 5'*, which was issued by the UK Civil Aviation Authority (CAA) on 16 June 1995. This permitted, subject to certain conditions, the use of the aircraft for "*free-fall, and static-line parachuting by persons*". One of the conditions for such operation as outlined in the supplement states that "*all seats, except the port forward pilot's seat must be removed*".

Figure No. 1 below illustrates how the skydivers, all of whom were facing rearwards, were carried on the aircraft during the accident flight. One of the Tandem Masters was seated with his back/parachute pack against the wooden structure used to block off the right hand foot well area, leading to damage to this structure during the forced landing (**Photo No. 2**).

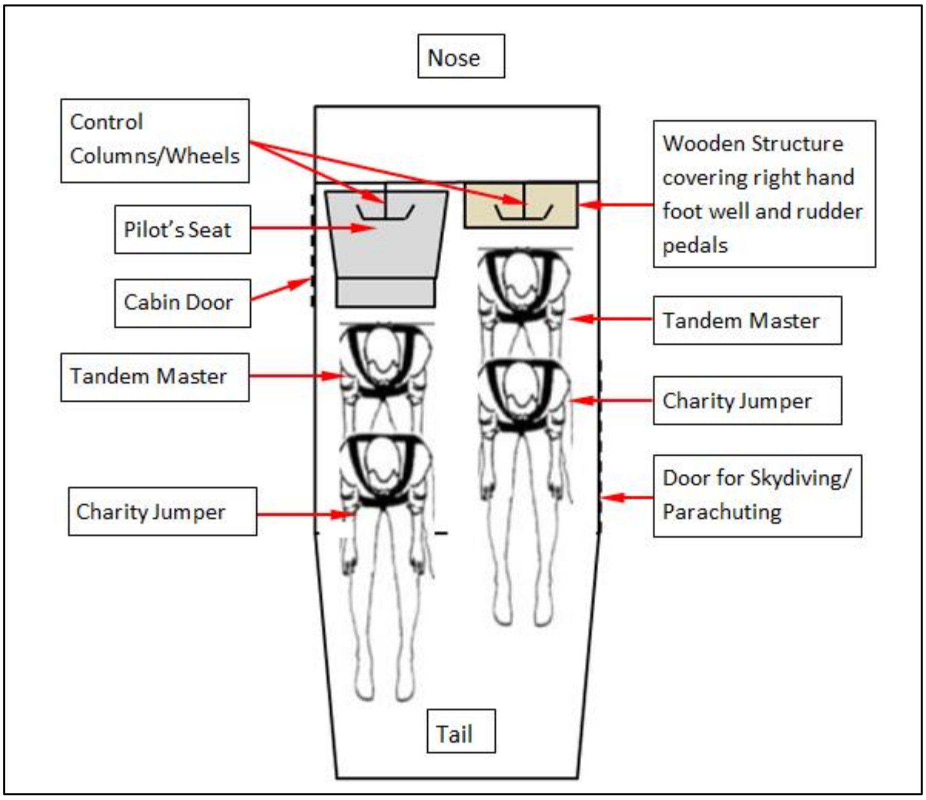


Figure No 1: Passenger layout on G-SKYE (Illustrative purposes only).

1.10.2 Occupant Restraint

Except for the Pilot's seat harness, there was no provision for the restraint of occupants on board the aircraft in its parachute operations configuration.

Upon examination, three seat belts were found attached to the interior of the side wall of the aircraft, but were tucked in behind the material lining the side wall. A single end-fitting, a tongue (the part that is pushed into the buckle/receiver when fastening the seat belt), was installed on each belt. A fourth belt was found fitted to the cabin ceiling, forward of the right hand door. These belts were not related to parachute operations but were likely left fitted to the aircraft when the normal passenger seats and the buckles/receivers for each belt were removed to facilitate parachute operations.

1.10.3 Certification

The Airworthiness Review Certificate (ARC) for the aircraft was certified by a UK CAA approved Continuing Airworthiness Management Organisation (CAMO) on 25 October 2013 and at the time of the accident was valid until 24 October 2014. The associated Airworthiness Review Report included a checklist item to verify that "*The aircraft in its current configuration complies with the type design approved by EASA"*[10]. This was ticked and a footnote, "FAA"[11], was added by the person who carried out the airworthiness review, indicating that the aircraft complied with an FAA Type Certificate, the reference number for which had also been entered on the checklist ('*A4CE, Revision 48*', dated 20 December 2011). The Airworthiness Review Report also included a checklist item to "*confirm all modifications and repairs have been approved in accordance with Part 21"*[12].

A certificate entitled '*Permission for a Parachute Dropping and Training Centre*' was issued by the IAA to the Irish-based skydiving club and was valid until 30 June 2014. It was stated on page two of the permission certificate that the skydiving club "*is competent to secure the safe operation of the aircraft specified in Schedule 1 hereto on flights for the purpose of parachute dropping operations and associated training for said parachute dropping operations for any such purpose*". G-SKYE was listed in '*Schedule 1*' of the certificate which was signed by an IAA officer on 17 May 2014.

1.11 Aircraft Maintenance History

1.11.1 General

An Annual Inspection was completed on the aircraft on 5 November 2013 at 4,169 hours and a 50 hour inspection, which included an engine oil and oil filter change, was completed on 12 May 2014 at 4,178 hours. Both inspections were performed by a UK-based Maintenance/Repair Organisation (MRO) which was approved in accordance with EASA Part 145[13] by the UK CAA.

1.11.2 Airworthiness Directives

1.11.2.1 Crankshaft Airworthiness Directives

The Investigation reviewed the Airworthiness Directives (ADs) that relate to the engine crankshaft as fitted to TSIO-520 engines (the engine type fitted to G-SKYE). **Table No. 3** refers.

[10] **EASA:** European Aviation Safety Agency.
[11] **FAA:** Federal Aviation Administration of the United States of America.
[12] **EASA Part 21:** Legislated by Regulation (EU) No 748/2012 containing, *inter-alia*, the requirements to be complied with during aircraft design and modification.
[13] **EASA Part 145:** To obtain European regulatory authority approval, an aircraft Maintenance/Repair Organisation, must be in compliance with the standards contained in EASA Part 145.

AD Number	Description	Notes
FAA AD 97-26-17 (Effective 9 March 1998)	Inspection for correct crankshaft manufacturing process.	Not Applicable due date of manufacture (March 2003).
FAA AD 99-19-01 (Effective 30 September 1999)	Inspection of crankshaft for cracking.	Not Applicable due date of manufacture.
FAA AD 2000-23-21 (Effective 12 December 2000)	Crankshaft Material Inspection by taking a core sample at the crankshaft propeller flange.	Not Applicable due date of manufacture. However, the crankshaft bears evidence of a core sample taken at the propeller flange.

Table No. 3: Crankshaft Airworthiness Directives.

1.11.2.2 Other Airworthiness Directives

G-SKYE had been leased by the Irish-based skydiving club because the aircraft normally operated by them, which had a similar engine type to that fitted to G-SKYE, was affected by a recently published FAA AD (2014-05-29) and required extensive engine maintenance. The AD became effective on 25 April 2014 and superseded an earlier AD, 2009-16-03 (dated 9 September 2009). Both the new and superseded ADs were issued due to reports of cracking in the area of the exhaust valves and the separation of cylinder heads from the barrels of certain cylinder assemblies produced by a particular manufacturer. The initial AD required a detailed inspection for cracking to be carried out and the performance of an engine compression test, both of which were required to be repeated every 50 flight hours. The revised AD, 2014-05-29, expanded the applicability to other engine types and also added an ultimate cylinder life of 12 calendar years.

The Airworthiness Review Report associated with the ARC for G-SKYE was signed on 25 October 2013 and indicated that all applicable ADs had been incorporated. At the time of the Airworthiness Review, the initial AD, 2009-16-03, was applicable. However, when the maintenance records were reviewed, no evidence could be found that this AD had been complied with. The revised AD, 2014-05-29, was issued on 25 April 2014, after the Airworthiness Review had been carried out. This AD was applicable when the last 50 hour inspection was carried out on 12 May 2014, but no record of its completion was found.

1.12 Engine Details

1.12.1 General

The engine fitted to G-SKYE was manufactured by Teledyne Continental Motors (TCM) (model number TSIO-520-M (7), serial number (S/N) 291574-R). It is a horizontally opposed six-cylinder, air-cooled, fuel-injected and turbo-charged unit. The engine cylinders are numbered as follows: one, three and five on the right hand side when viewed from the cockpit, with number one being the most aft, and two, four and six on the left hand side, with number two being the most aft. The engine was fitted with a three-blade, aluminium alloy, constant-speed propeller.

On this engine type, all crankshaft components are numbered from aft to forward. The number four main journal (M.J. #4) is the 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 (**Section 1.12.11** refers). The Engine Manufacturer refers to the crankshaft webs as '*cheeks*', and the big-end journals as '*rod journals*' (**Figure No. 2**).

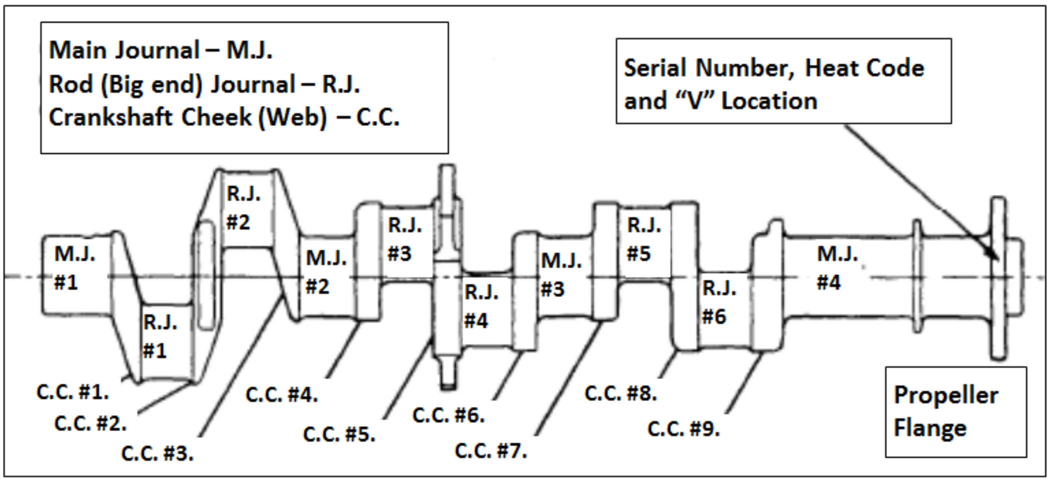


Figure No. 2: Crankshaft component identification (Ref. Teledyne-Continental *CSB 96-8*).

1.12.2 Maintenance History

11 1.12.2.1 Engine Overhaul

Engine S/N 291574-R was removed from G-SKYE on 16 August 2008. This is recorded in both the aircraft and the engine log books. It was received for overhaul on 5 March 2009 by an MRO. The MRO was approved by the UK CAA in accordance with EASA Part 145.

The 'bottom end'[14] of another engine, S/N 513267, was received for overhaul by the same MRO, a number of years previously, on 6 June 2003. The overhaul for this 'bottom end' was completed on 7 August 2003. Records indicate that the S/N of the crankshaft fitted to the 'bottom end' was N03CA233, which denotes that it was manufactured in March 2003. A form (*134A, issue 3*) included in the engine work pack for engine S/N 513267, contained the measurements for the crankshaft main journals and rod journals. These are included in **Appendix A** in **Table No. A1** and **No. A2** respectively. Measurements for the main bearing inside diameters were also recorded in the work pack as were the calculated clearances between the crankshaft main journals and the main bearing inside diameters. These were within engine overhaul manual limits. (See **Appendix A, Table No. A3**).

[14] **Bottom end:** A crankcase assembly, including bearings, crankshaft, connecting rods, camshaft and timing gears.

Details for the crankcase main bearing housing/saddle diameters of engine S/N 513267 were recorded on another form within the work pack (*137A, issue 1*). These are included in **Appendix A** in **Table No. A4**. It was stated on the form that there were “*no limits listed in overhaul manual*”. The condition of the main bearing housings/saddles and crankcase joint faces was noted as being “*satisfactory*”.

Following overhaul, the ‘bottom end’ was placed in storage for a number of years. Records indicate that it was inhibited[15] every three months while in storage. The ‘bottom end’ of engine S/N 513267 was then used during the overhaul of G-SKYE’s engine (S/N 291574-R). The Authorised Release Certificate for engine S/N 291574-R was signed on 24 July 2009.

When asked by the Investigation to describe the process for assembling an engine ‘bottom end’, the engine overhauler explained that because the engine cylinders are not fitted in such circumstances, ‘slave’ nuts are used in conjunction with the normal through-bolts. These permit the assembly of the crankcase halves. During final engine assembly, the slave nuts are sequentially removed, the cylinders are installed and the correct nuts are fitted and torqued. The engine overhauler advised that all fasteners are torqued at “*all positions on both sides of the engine at all times*” and are “*dual-inspected*”.

1.12.2.2 Date of Installation

There were no entries in either the engine or airframe log books from 16 August 2008 (the date recorded for the engine removal) until 24 June 2009. The ‘*Time Run Since New or Complete Overhaul*’ as recorded in the engine log book was zeroed on 24 June 2009, with the subsequent hours of operation being recorded from this date. However, as stated above, the release certificate for this engine was not certified until 24 July 2009.

A note that the overhauled engine had been fitted to the airframe (G-SKYE) was entered in the engine log book adjacent to an entry made for an Annual Inspection that was dated 15 April 2010. The file reference for the Annual Inspection was recorded as “*Misc 10-9*”. The note in relation to the engine installation also refers to this file number, which, based on a review of previous dated entries, indicates that the installation was performed in 2010. However, numerous engine log book entries for engine running time were made between 24 June 2009 and 15 April 2010, by which date, a total running time of 14 hours and 35 minutes had been recorded.

The MRO where the engine was installed has since ceased trading and the date that engine S/N 291574-R was refitted to G-SKYE could not be positively established. A total engine operating time of 98 hours was recorded in the engine log book from 24 June 2009 until the date of the accident.

[15] Inhibited in this context means protected from corrosion.

1.12.2.3 Periods of Inactivity

As indicated in **Section 1.10.1, Table No. 2**, from August 2009 there were extended periods during which the aircraft was not flown. A Service Information Letter, SIL 99-1, was published by the Engine Manufacturer on 25 March 1999. The SIL states that "*corrosive attack can occur in engines that are flown only occasionally* […]" and that "*the best method of reducing the likelihood of corrosive attack is to fly the aircraft at least once every week for a minimum of one hour".* The SIL contains guidelines for engine preservation/corrosion prevention, to be performed when an aircraft is not flown for periods of between 30 and 90 days. A separate procedure is also documented which is to be used when an aircraft is not operated for 90 days. There was no record of any engine or aircraft preservation actions taken on G-SKYE prior to these periods of inactivity, although it was reported by the UK-based aircraft operator, who normally operated the aircraft, that the propeller was rotated weekly. It was also reported that he "*would run the engine and often taxi it round the airfield every month*". This operator also stated that there were no propeller strikes since the overhauled engine was fitted.

1.12.2.4 Other Maintenance

The turbocharger and associated waste-gate were replaced in November 2013 during the Annual Inspection. The MRO where the components were fitted advised the Investigation that the replacements were carried out in accordance with the Manufacturer's Maintenance Manual and that ground runs were conducted to ensure maximum boost pressure was not exceeded and that fuel flows were correct. It was stated that the aircraft was test flown and that no adjustments were required.

Except for scheduled maintenance, the log books indicated that no other engine work was performed since overhaul.

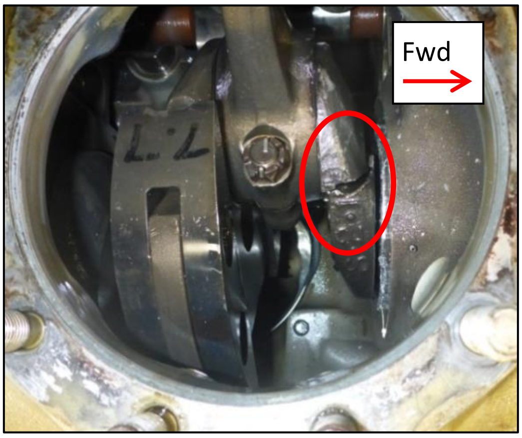
1.12.3 Engine Disassembly and Inspection

The aircraft was transported to the AAIU's facility at Gormanston, where, with the assistance of a Licensed Aircraft Engineer, the engine was removed and disassembled.

The exhaust manifold at the exhaust port for the number two cylinder was found to be completely broken from the port. This was determined to be a pre-existing defect due to evidence of soot deposits on the adjacent cylinder head and pushrod housing.

The engine sump was removed and was found to contain a large amount of metallic debris. The engine oil pump inlet strainer was present and intact; however, it was contaminated with metallic debris, as was the engine oil filter. In addition, the oil pump contained traces of metallic debris.

It was confirmed that the crankshaft was broken between the number three main bearing journal and number six cheek, aft of cylinders five and six (**Photo No. 3** and **No. 4**). Mechanical deformation and heat tinting were present on the cheek and journal.



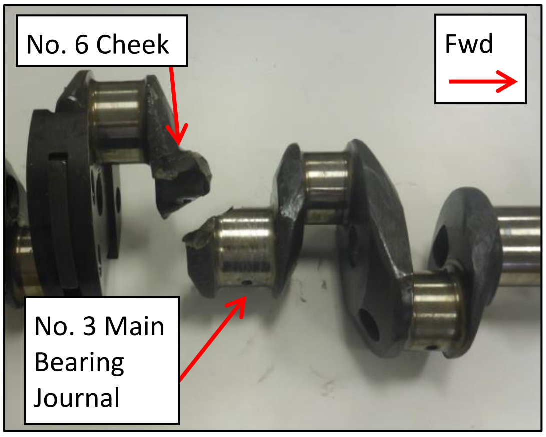


Photo No. 3: Broken crankshaft as seen with the number four cylinder removed.

Photo No. 4: Crankshaft fracture between the number 3 main bearing journal and the number six cheek (web).

The through-bolts which secure the crankcase halves and hence the crankshaft, were checked prior to disassembly and appeared to be correctly torqued, as did all other crankcase and cylinder retention bolts. The crankcase halves were then separated and the crankshaft was removed. The S/N of the crankshaft found fitted was N03CA233, which matched the S/N recorded in the work pack for the overhaul of the 'bottom-end'. The number three main bearing was found to be destroyed and the associated bearing housings/saddles, which are part of the crankcase halves, were found to be badly damaged (**Photo No. 5** and **No. 6**). All other main and rod (big-end) bearings were intact with no evidence of corrosion.

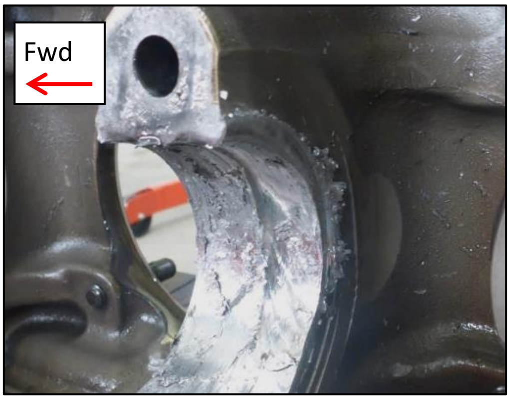


Photo No. 5: Damage to the number three bearing housing/saddle on the 1, 3, 5 crankcase half (viewed from the crankshaft side).

Photo No. 6: Damage to the forward face of the number three bearing housing on the 1, 3, 5 crankcase half (viewed from the cylinder side).

Evidence of fretting[16] was found on the mating faces of the main bearing housings/saddles. In addition, indentations caused by the bearing tangs on the main bearings fitted to the opposite crankcase were noted on some of these faces (**Photo No. 7**). There was also evidence of fretting on the crankcase parting surfaces (**Photo No. 8**).

[16] **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.

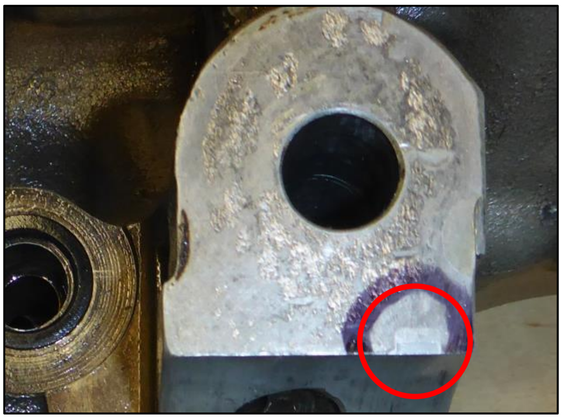


Photo No. 7: Fretting on the number four main bearing housing/saddle face and indentation (circled) caused by the tang on the opposite bearing.

Photo No. 8: Fretting on the crankcase parting surface.

Before the crankcase halves had been separated during engine disassembly, a white-coloured sealant was evident at the crankcase parting surfaces adjacent to the camshaft (**Photo No. 9**). When the crankcase halves were separated, the white-coloured sealant was found on the parting faces of each crankcase half (**Photo No. 10**).

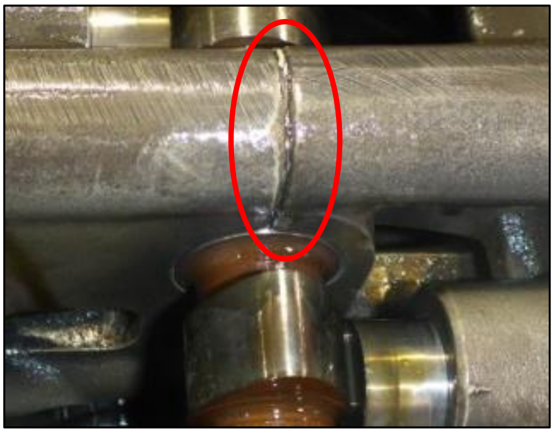


Photo No. 9: Sealant visible on crankcase parting surface adjacent to camshaft, before engine disassembly.

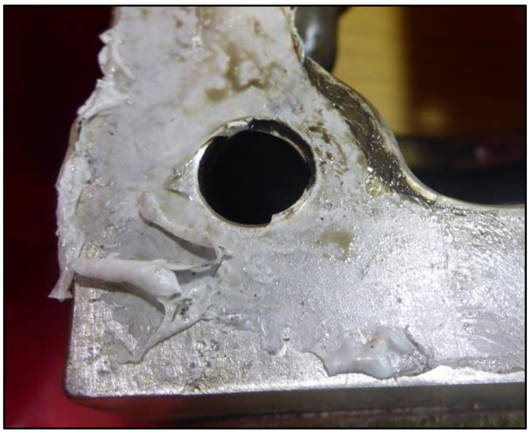


Photo No. 10: Sealant visible on crankcase parting surface following separation of crankcase halves.

The common oil gallery in the crankcase was inspected and found to be clear. The galleries which supply oil to the main bearings are fed from this common gallery. The galleries supplying the one, two, four and five main bearings were found to be obstruction-free. Apart from the damage to the bearing housing saddle area, the gallery supplying the number three main bearing was also found to be obstruction-free.

The serial numbers of the engine cylinders matched those contained in the engine work pack, confirming that these were not replaced since engine overhaul.

1.12.4 Engine Manufacturer

As part of the investigation process, the Engine Manufacturer was advised of the accident and was informed of the initial finding that the crankshaft was broken. The Manufacturer stated that "*this type of problem is usually caused by the overhauler putting some type of material on the case mating surfaces that does not allow a solid fit between the case halves, and allows movement, which will cause either a spun bearing or the main bearing to be impact damaged until it spreads to the point where it contacts the crankshaft cheek and cause[s] the crankshaft to break*".

Following the disassembly of the engine, a photographic report on the engine condition and associated findings was provided to the Manufacturer which included photographs of the sealant found. In response, the Manufacturer stated that the sealant material shown in the photographs "*would be more than enough to cause the damage*".

The Manufacturer specifies the use of silk thread to perform the sealing function on the crankcase parting surfaces. Silk thread was not found to be present during engine disassembly.

1.12.5 Metallurgical Analysis of Removed Crankshaft

1.12.5.1 General

The crankshaft was sent to a specialist laboratory for detailed metallurgical analysis. The resulting report highlighted that the crankshaft fractured due to the initiation and propagation of multiple fatigue cracks through the wall thickness of the number three main journal (**Photo No. 11**).

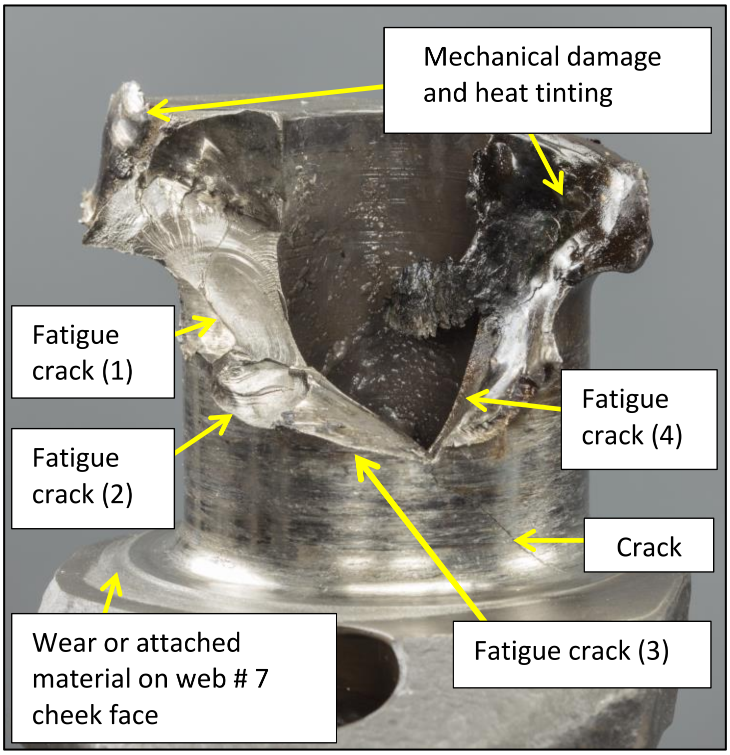


Photo No. 11: Forward section of fractured number three main journal.

A number of longitudinal surface-breaking cracks were also observed on the surface of the fractured journal (**Photo No. 12**). Examination of fatigue crack (2) on the forward section of the crankshaft and the opening of one of the longitudinal cracks indicated that the origin of the fatigue cracks could be associated with the longitudinal cracks (**Photo No. 13**).

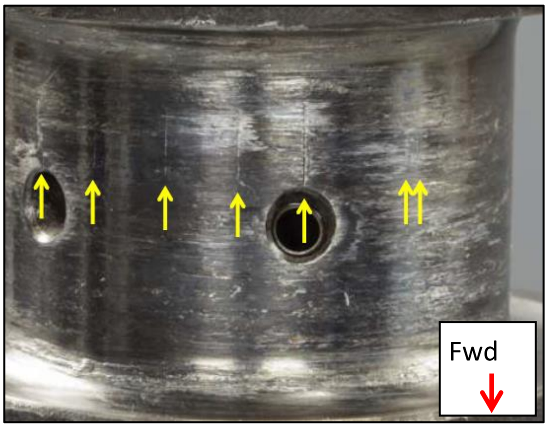


Photo No. 12: Longitudinal cracks present on fractured number three main journal.

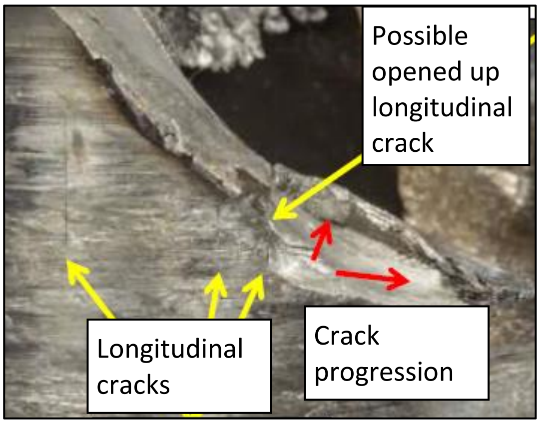


Photo No. 13: Origin of fatigue crack (2) from what appears to be one of the longitudinal cracks.

Smearing and adhesion of material were found to be present on the surface of the number three main journal. Analysis of this material revealed the presence of aluminium and lead, with traces of silicon and copper. In addition, wear damage and adhered material were found to be present on the aft face of the number seven cheek. Analysis of this material also revealed the presence of lead. The metallurgist's report stated that the deposited material on the fractured main journal surface and on the number seven cheek was similar in composition. The metallurgist noted that the aluminium-rich material was most likely from contact with the crankcase or bearing housing/saddle and that the lead-rich particles were associated with the break-up of the main journal bearing.

As part of the metallurgical analysis, the diameters of the crankshaft main and rod (big end) journals were measured.

The dimensions obtained and the overhaul manual limits for the main journals are included in **Appendix A, Table No. A1**. The diameters for the number one, two and four main journals were found to be less than the minimum in-service limit. The number one, two and four main journals showed some light radial (circumferential) scoring, but there was no evidence of thermal distress, cracking, corrosion or excessive localised wear.

The dimensions obtained and the overhaul manual limits for the rod journals are included in **Appendix A, Table No. A2**. The diameters of all but one of the rod journals were found to be less than the minimum in-service limit. There was no evidence of thermal distress, cracking, corrosion or excessive localised wear, other than some light radial circumferential scoring.

1.12.5.2 Metallography

Two polished micro-sections from the crankshaft were analysed – one from the fractured number three main journal and one from the number two main journal (used as a reference piece). Examination of the core microstructure showed the material to exhibit a tempered martensite[17] microstructure (normal). No differences in core microstructure were observed between the fractured journal and the reference piece. The elemental composition of the crankshaft material was found to be consistent with AISI[18] 4340 type steel, a material typically used for crankshaft manufacture. No metallurgical defects were observed in the samples examined from the crankshaft material.

A hardness profile was acquired from the external surface of the main journal into the core material on both micro-sections. The results showed that the core material hardness of the fractured journal and of the reference piece taken from the number two main journal were similar. Both profiles showed an increase in hardness towards the surface of the journal. It was noted that this increase was more rapid on the fractured journal.

In addition to the adhered layer on the fractured journal, a thin layer described by the metallurgist as a "*transformed layer*"[19] was also found to be present and below this, a diffusion zone. It was stated in the metallurgist's report that "*the formation of a transformed layer at the surface of the fractured main journal is indicative of localised heating of the journal. The smearing and build-up of material on the journal surface are indicative of metal to metal contact, which would result in localised heating of the journal surface*".

There was no evidence of a nitride layer[20] on the fractured journal. However, it was noted that "*the absence of any nitride layer on the external surface of the fractured journal and the measured increase in hardness of the transformed layer is consistent with overheating driving a thermal transformation/diffusion process".*

1.12.5.3 Metallurgical Analysis Conclusions

In conclusion, the report stated, *inter-alia*, that "*It is suspected that localised thermal expansion of the* [number three] *journal has resulted in the formation of longitudinal cracks in the brittle surface layer of the journal, these surface cracks have initiated a number of fatigue cracks that have propagated through the wall thickness of the journal resulting in final fracture of the crankshaft".*

A copy of the metallurgist's report was sent to the Engine Manufacturer for comment. In response, the Manufacturer's metallurgist stated that he believed the fracture was the result of *"bearing shift, probably caused by a lack of torque on the thru bolts*".

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[17] **Martensite:** Refers to a very hard steel crystalline structure. Tempering is usually performed after hardening, to reduce some of the excess hardness.
[18] **AISI:** American Iron and Steel Institute.
[19] **Transformed Layer:** When a martensitic steel is subjected to localised overheating above the original tempering temperature of the steel, this typically results in a localised transformation of the steel to form under-tempered martensite.
[20] **Nitride Layer:** Formed during nitriding, which is a case-hardening process that diffuses nitrogen into the surface of a metal to create a nitride layer.

1.12.6 Inspection of Crankcase Halves

The Investigation verified that the serial number of the crankcase was the same as that recorded in the work pack (6D590) for the 'bottom end' overhaul.

In an attempt to measure the effect of the fretting observed on the main bearing clamping faces, the crankcase halves were sent to an approved engine overhaul facility for detailed examination. At this facility, the sealant was removed from the parting surfaces of the crankcase halves and they were reassembled. All bolts were torqued in accordance with the Manufacturer's requirements. The internal diameters of the number one, two, four and five crankcase main bearing housings/saddles (without the bearing shells fitted) were measured. It was not possible to measure the bearing bore for the number three main bearing due to the damage present. The results are contained in **Appendix A, Table No. A4.**

When average values were applied to the figures obtained, the number one bore was found to be 0.0007 inches less than the diameter recorded at overhaul. The number two bore was found to be 0.0002 inches less and the number four bore was found to be 0.0003 inches less than the respective values recorded at overhaul. The average diameter of the number five main bearing bore was 0.001 inches greater than what was recorded at overhaul.

1.12.7 Engine Overhaul Procedures

The instructions for the assembly of the crankcase halves are contained in the Engine Manufacturer's engine overhaul manual. Maintenance personnel are instructed to "*Spread a thin film of No. 3 Aviation Permatex on the left crankcase parting flange. Lay lengths of No. 50 silk thread on parting flange*". In addition, the Engine Manufacturer published a Service Information Letter, SIL 99-2 on 29 March 1999, entitled '*Current listing of sealants, lubricants, & adhesives authorized by TCM*'. This SIL was current at the time of the engine overhaul and listed the sealants that were authorised for use during engine maintenance and overhaul of TCM engines.

The sealants authorised for use on the crankcase parting surfaces included '*Permatex Aviation Grade 3D* and *#641543 Silk Thread*' and '*#646942 Gasket Maker or Loctite Gasket Eliminator 515 Sealant*'. This SIL also included detailed instructions and a diagram showing how to use the sealants and silk thread on the crankcase parting surfaces. The diagram indicated that no sealant or silk thread is required on the bearing saddle mating faces. A warning was included which highlighted that the silk thread and '*Permatex*' should only be used as illustrated (**Figure No. 3**). The Manufacturer advised the Investigation that the '*Permatex*' is "*only used to hold the silk thread in place*".

WARNING

Apply thread and permatex only as illustrated.

Figure No. 3: Warning contained in SIL 99-2 regarding sealant application.

The SIL was revised on 17 October 2005 (SIL 99-2B). However, the sealants authorised for use on the crankcase parting surfaces remained unchanged. The SIL was further revised on 16 September 2014 (SIL 99-2C) and now includes enhanced sealant and silk thread application diagrams. The diagrams utilise colour coding to indicate where the sealant and thread is required and where it is prohibited (**Figure No. 4**).

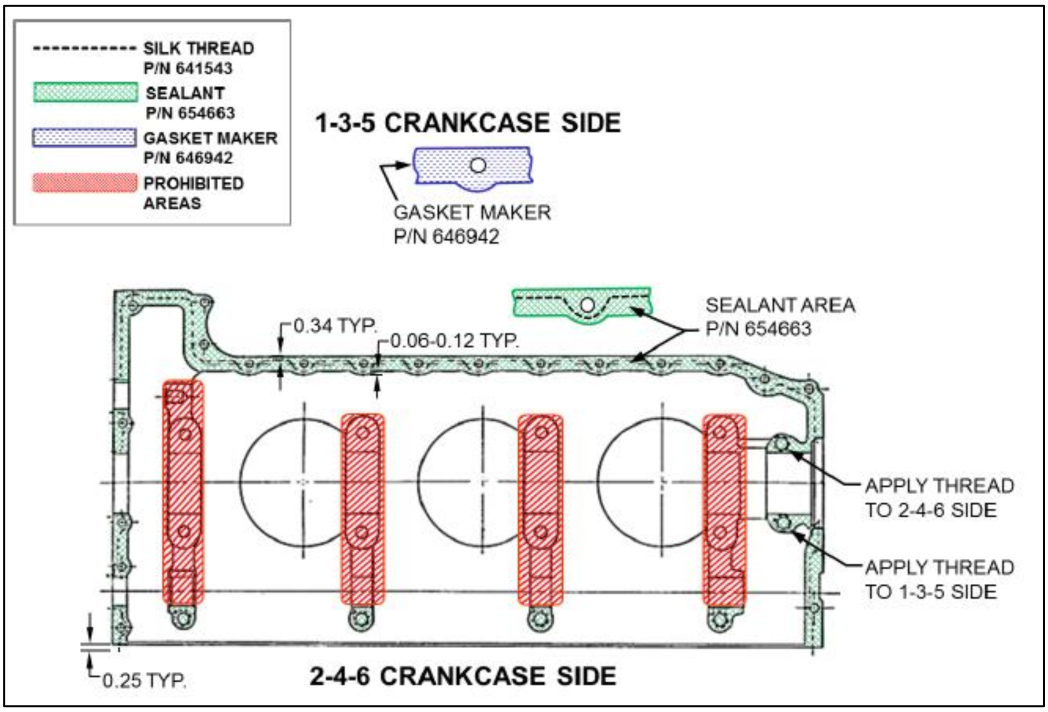


Figure No. 4: Revised sealant and thread application diagram as contained in SIL 99-2C.

Service Bulletin SB 96-7B, entitled ‘*Torque Limits*’, was issued by the Engine Manufacturer on 10 January 1999 and revised on 8 February 2005. It was valid at the time of engine overhaul and included a warning which stated that the use of sealants other than those specified by the Engine Manufacturer can cause incorrect torque application and can lead to engine damage or failure (**Figure No. 5**).

WARNING

THE USE OF SEALANTS OR LUBRICANTS OTHER THAN THOSE SPECIFIED BY TCM ON MATING THREADS AND BETWEEN MATING SURFACES CAN CAUSE INCORRECT TORQUE APPLICATION AND SUBSEQUENT ENGINE DAMAGE OR FAILURE.

Figure No. 5: Warning contained in SIL 99-7B regarding the potential for engine damage or failure if unapproved sealants are used.

1.12.8 Laboratory Analysis of Sealant

A sample of the sealant found on the crankcase parting surfaces was sent for analysis to a specialist laboratory. A tube of RTV[21]-102 sealant which can be used on the crankcase parting surfaces of engines manufactured by another manufacturer was also sent to the laboratory for comparison purposes. The laboratory concluded that "*the sealant sample was identified as a silicone type by library matching with a correlation value of 0.93. Comparison to RTV-102 gave a correlation value of 0.99*". RTV-102 is not approved by TCM for use on its engines (the engine type fitted to G-SKYE).

The 'Tack-Free Time' for RTV-102 as recorded on the product's Technical Data Sheet is 20 minutes.

1.12.9 Use of Sealant during Engine Overhaul

The MRO advised that they do not use RTV-102 on the crankcase parting surfaces of TCM engines. The part number and batch number for the sealant used are not listed in the MRO's work pack for G-SKYE's engine.

1.12.10 Special Airworthiness Information Bulletins and Safety Information Bulletins

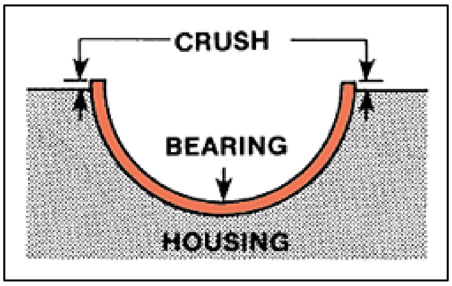
A Special Airworthiness Information Bulletin (SAIB) is an information tool used by the FAA that alerts, educates and makes recommendations to the aviation community. SAIBs contain non-regulatory information/guidance that does not meet the criteria for an Airworthiness Directive (AD). Safety Information Bulletins (SIB) are published by EASA for similar reasons and these SIBs can refer to SAIBs.

A search of the SAIB and SIB online databases revealed no bulletins relating to the use of incorrect sealant during overhaul of TCM engines.

1.12.11 Crankshaft Bearings: Installation and Lubrication

Crankshaft main bearings comprise of two halves or shells, manufactured from a metal alloy, usually containing lead. The outside diameter of the bearing shell is slightly larger than the diameter of the crankcase bearing housing/saddle. As a result, when a bearing shell is installed in its housing during engine reassembly, its edges normally stand slightly proud of the housing. The amount the edges stand proud is known as bearing crush/nip (**Figure No. 6**). When the crankcase halves are bolted together, and the through-bolts are tightened to the correct torque value, the bearing is pressed into its housing. This results in an interference fit which prevents bearing movement during engine operation. In addition, each bearing shell normally contains a lug/tang, which sits into a dedicated notch in the bearing housing/saddle and ensures the correct location of the bearing during assembly and also prevents bearing movement. The Engine Manufacturer's Service Bulletin, SB 96-7B, contains a '*Caution*' outlining that the through bolts must be torqued on both sides to prevent bearing shift (**Figure No. 7**).

[21] **RTV:** Room Temperature Vulcanisation. An RTV sealant cures (sets) at room temperature.



> CAUTION: Failure to torque through bolt nuts on both sides of the engine can result in a loss of main bearing crush, main bearing shift and engine failure.

Figure No. 6: Bearing Crush/Nip.

Figure No. 7: Caution contained in SB 96-7B relating to correct torqueing of through-bolts.

Main engine bearings rely on hydrodynamic lubrication to prevent metal to metal contact between the surface of the rotating crankshaft and the stationary bearing when the engine is running. When the engine starts to run, oil under pressure is supplied from a gallery through a hole in the bearing shell. The oil is 'dragged' by the rotating crankshaft and forms a wedge which supports the crankshaft in the bearing (**Figure No. 8**). For hydrodynamic lubrication to occur, a certain amount of clearance must exist between the crankshaft journals and the bearings. This clearance is checked during engine assembly. Work pack records indicate that the clearance at engine overhaul was within limits (**Section 1.12.2.1** and **Appendix A, Table No. A3**).

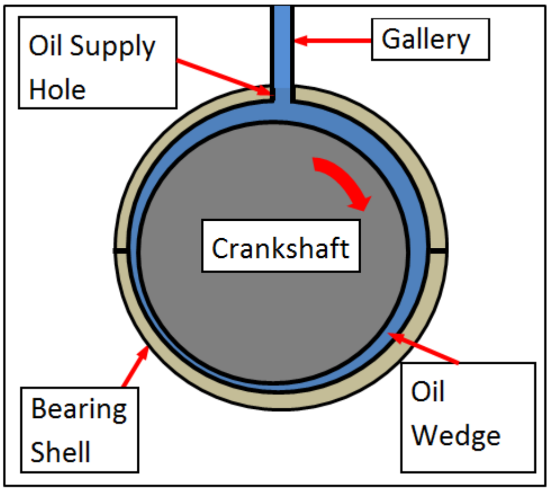


Figure No. 8: Hydrodynamic Lubrication.

1.13 Other Occurrences involving Crankshaft Failures

1.13.1 Accident to Cessna U206G at Bansankusu Airfield, Democratic Republic of Congo

The Belgian Air Accident Investigation Unit published a report[22] in 2012, which related to an occurrence on 9 May 2011 on approach to the Bansankusu airfield that also involved a Cessna U206G which was fitted with a Teledyne Continental IO-520-F engine (similar to that fitted to G-SKYE). In this event, the engine also sustained a broken crankshaft. The engine had operated for 1,405 hrs since overhaul.

[22] **Report Reference:** Belgian AAIU-2011-23-FZEN-OO-A**

The associated report noted that a white-coloured sealant had been used on the crankcase parting surface. A white-coloured sealant had also been used on the bearing housing/saddle mating faces, where no sealant is permitted. The probable cause of the failure was recorded in the report as:

"*The installation, during the last engine overhaul, of an unapproved sealant on the parting surfaces of the crankcase halves. In particular, using anything else other than Permatex and Silk string around the through bolts mating surface will cause over time chafing of the crankcase halves, bearing looseness and finally crankshaft rupture*".

1.13.2 US National Transportation Safety Board (NTSB) Investigation Reports

NTSB investigation reports SEA00LA173 (August 2000) and FTW01LA210 (September 2001) relate to crankshaft failures on Teledyne Continental Motors 520 series engines.

In investigation SEA00LA173, it was found that some form of sealant had been applied to the mating faces of the main bearing housings/saddles during the last crankcase reassembly. Fretting was also observed on the mating faces of main bearing housings/saddles. The investigation determined that the crankshaft failed "*due to fatigue, which initiated from the surface at the aft cheek radius of the number two centre main crankshaft journal*", and that "*shifting of the number two main bearing had produced scoring in the cheek radius, leading to fatigue crack initiation*". It was noted in the NTSB's report that the Manufacturer's overhaul instructions "*specifically forbid application of any sealing material on the main bearing saddle mating faces*". The engine had been overhauled approximately 18 months prior to the accident.

Regarding investigation FTW01LA210, it was identified that silicone sealant was used on the "*mating surfaces of the crankcase halves*" which resulted in improper torque on the bolts which secure the crankcase halves together, vibration, and the subsequent failure of the number two main crankshaft bearing and the fracture of the crankshaft. It was stated in the report that fretting was observed "*on the crankcase mating surfaces and on the main bearing bosses* [housings/saddles]". The engine had operated for 777 hours since last overhaul.

1.14 Parachute Operations

Except for the Pilot's seat harness, there was no provision for the restraint of occupants on board G-SKYE. This Investigation is a Safety Investigation and in that context, in addition to investigating the probable cause of the engine failure in this accident, the Investigation also decided to review the legislation and guidance material associated with the restraint of occupants on board parachute operations aircraft. A number of other accidents involving parachute operations aircraft in other States and in which the restraint of occupants was considered by the respective investigations are also reviewed.

1.14.1 Legislation, Requirements and Guidance Material Regarding Restraint of Occupants

1.14.1.1 European Legislation

Within Europe, EASA is responsible for promoting common standards of safety and environmental protection in civil aviation and assists the European Commission in the development of EU Regulations pertaining to aviation.

Currently, Regulation (EU) No 965/2012 (Air Operations) of 5 October 2012 lays down the technical requirements and administrative procedures related to air operations pursuant to Regulation (EC) No 216/2008 of the European Parliament. States had the option not to apply the provisions of Regulation 965/2012 until 28 October 2014. Ireland and many other states chose this option. Therefore, at the time of the accident, the previous Regulation, 859/2008 (EU-OPS), was in force in Ireland.

It was stated in OPS 1.001 (applicability) of 859/2008 that it applied to commercial air transport and did not apply to "*parachute dropping*" flights or to flights connected with "*aerial work activity*". Therefore, Section OPS 1.730 of the regulation which required aircraft to be equipped with a safety belt or a safety harness for each passenger and Section OPS 1.320 requiring the safety belt or harness to be secured before take-off and landing or whenever deemed necessary, were not applicable to the accident aircraft.

Regulation 965/2012, now in force, also applies to commercial air transport operations and contains similar requirements to 859/2008 regarding seat belts and safety harnesses for such operations. Regulation (EU) No 800/2013 amends 965/2012. This amendment includes the addition of two new Annexes to 965/2012 (Annex VI and Annex VII).

Regulation (EU) No 379/2014 is a further amendment to 965/2012 which, *inter-alia,* added a new Annex, Annex VIII, '*Specialised Operations*' (SPO). This Annex applies to any specialised operation where the aircraft is used for specialised activities (Aerial Work) and includes legislation pertaining to parachute operations (PAR). Member States have the option of not implementing this regulation until 2017. Ireland chose this option.

Pertinent sections of the new Regulation and related information are included at **Appendix B**. The new Regulation includes the requirement in Section *'SPO.GEN.106 (b)'* that "*Except for balloons, during critical phases of flight or whenever deemed necessary by the pilot-in-command in the interest of safety, the task specialist shall be restrained at his/her assigned station unless otherwise specified in the SOP* [Standard Operating Procedure]". A task specialist is defined in Regulation (EU) No 379/2014 as "*a person assigned by the operator or a third party, or acting as an undertaking, who performs tasks on the ground directly associated with a specialised task or performs specialised tasks on board or from the aircraft".* Parachutists are considered to be task specialists. Regarding parachute operations aircraft, Section '*SPO.SPEC.PAR.110 Seats*' (Annex VIII, sub part E), states that "*the floor of the aircraft may be used as a seat, provided means are available for the task specialist to hold or strap on*".

EASA publishes Certification Specifications (CS) which set out minimum technical standards for aircraft, including the specifications and design criteria for restraint devices (CS 23). These Certification Specifications do not apply to parachute operations aircraft. The criteria for EASA approval for such aircraft are included in an EASA '*Special Condition'* document (SC-023-div-01) which was issued on 6 July 2009 and applies to approval applications submitted after that date. It states, *inter-alia,* that "*the following items must be substantiated: Seating/accommodation and restraints approved for use during take-off and landing*. […]. *Protection of the control systems on board from contact of parachutists or their material*. […]". No technical requirements/design criteria for restraints are included.

1.14.1.2 IAA Guidance Material and Associated Legislation

In 2010, the IAA produced a guidance document for parachute operations in Ireland, entitled '*Parachuting*'. Chapter 3, Section 18 of this document relates to '*Safety in the Aircraft*' and states in paragraph 18.5 that "*Where parachutist restraints are fitted they must be used during take-off and landing or otherwise as required by the aircraft Flight Manual or Flight Manual Supplement*". This requirement is specific to the use of restraints when installed on aircraft used for parachute operations. There is no requirement in the guidance material for restraints to be fitted in the first instance.

It is also stated in the guidance material that "*All parachute dropping from civil registered aircraft in Irish Airspace is regulated by the IAA and must be conducted in accordance with the requirements of Article 7 of Irish Aviation Authority (Rules of the Air) Order, 2004, S.I. No. 72 of 2004. The IAA Regulations state that when valuable consideration has been given or is promised for the carriage of passengers and the flight is for the purpose of dropping persons by parachute, then it is deemed to be aerial work; and that positioning and return flights made in connection with such flights are subject to the same requirements".*

An 'Aerial Work' aircraft is defined in the Irish Aviation Authority (Operation) Order*, S.I. No.* 61 of 2006 as "*an aircraft, not being a commercial transport aircraft, which is being flown for payment required to be made, or promised, to the operator of the aircraft in respect of the flight or of the purpose for which the flight is made*".

It should be noted that since the subject event, the IAA has published an '*Operations Advisory Memorandum*' (reference number 02/15, dated 3 July 2015) which contains information for "*persons engaged in parachute jumping in Ireland*". An extract from this publication is included at **Appendix C**.

1.14.1.3 IAA Approval

Article 7 of S.I. No. 72 of 2004 (Rules of the Air) states that "*A person shall not, except in the case of emergency, descend by means of a parachute from an aircraft flying within the State, unless the descent is made in accordance with a permission given by the Authority or by an organisation authorised by the Authority to issue such a permission and subject to any condition or limitations contained in such authorisation or permission, whether given by the Authority or by an authorised organisation*".

In accordance with this requirement, and as highlighted in **Section 1.10.3**, a certificate entitled '*Permission for a Parachute Dropping and Training Centre*' was issued by the IAA to the Irish-based skydiving club. In addition to the aircraft operated by the club, '*Schedule 1*' of the Permission contains a list of club personnel. The two Tandem Masters who were on board the aircraft at the time of the accident were listed in the schedule.

'*Schedule 2*' of the Permission contains the conditions to be met to ensure its continued validity. Condition 3 of this schedule states that "*Every flight under this permission shall be conducted in full compliance with the requirements of all relevant legislative requirements in force including Irish Aviation Authority regulations, national and local government regulations and the relevant provisions of the holder's operations, maintenance and flight manuals*".

1.14.1.4 IAA Letter relating to the Installation of Restraints

Under Section 58 (1) of the Irish Aviation Authority Act 1993, the IAA has the power to make orders and regulations relating to aviation.

The IAA issued a letter on 14 June 2010 to the Irish-based skydiving club relating to the aircraft normally operated by the club, a Cessna 185. The letter noted that there were no restraining devices fitted which would *"ensure that parachutists could not be displaced in the aircraft during a take-off run if the pilot had to stop suddenly*". The letter referred to the requirements of EU-OPS 1.320 (Regulation (EU) No 859/2008) regarding the use of seat belts/harnesses. However, as outlined in **Section 14.1.1.1**, Regulation No 859/2008 did not actually apply to parachute operations aircraft. The IAA's letter stated that "*the Authority is concerned for the safety of the parachutists on board* […] *and now requires that the* [Irish-based skydiving club] *install appropriate anchor points/pins to facilitate the operation of restraining devices on board the parachuting aircraft".* The IAA also requested that the Aircraft Operations Manual be amended to "*reflect this new operational procedure*". It was stated in the letter that "*the Authority requires this procedure to be effective within 90 days i.e. by 12 September* [2010]". The IAA advised the Investigation that at the time, similar letters were issued to other skydiving/parachuting clubs within Ireland.

The member of the Irish-based skydiving club who leased G-SKYE was interviewed by the Investigation. He said that it was uncommon for him to hire aircraft and that he only became aware that G-SKYE had no restraint devices fitted following its initial arrival at EIAB. He said that the aircraft "*was under the jurisdiction of the CAA* [UK], *I presume, coming into us and they were happy with the configuration of the aircraft*". He stated that the tandem masters were briefed that there were "*no restraints on G-SKYE and we weren't in a position to fit them…it was only in on a temporary basis it was coming in on hire*".

1.14.1.5 Parachute Association of Ireland

The Parachute Association of Ireland (PAI) develops and maintains standards for safety, training and operations for sport parachuting for PAI members and its affiliated centres. It is stated in the PAI's Operations Manual that affiliation shall be effected by an annual agreement between the PAI and an affiliated centre and that "*the basis of this annual agreement shall be an undertaking on the part of the parachuting centre to abide by the regulations specified in this Operations Manual* […]".

An annual agreement was in place between the PAI and the Irish-based skydiving club for the period from 1 January 2014 to 31 December 2014. As such, the Irish-based skydiving club was required to operate in accordance with the PAI's Operations Manual and with its own Flight Operations Manual which cross-referenced the PAI's manual.

Paragraph 4 of Section 9.2 of the PAI's Operations Manual, entitled '*Safety with Aircraft/Seat belts'*, states that: "*The Loadmaster or Jumpmaster is responsible for the orderly enplanement of his lift and for supervision and commands as necessary in the aircraft. All parachutists are under his command until they leave the aircraft and it is his responsibility* [*inter-alia*]:

- *To ensure all parachutists on-board have seat belts securely fitted and inform pilot before aircraft begins to role for take-off.*
- *To ensure all seat belts are removed and safely stowed at the recommended height for the aircraft type and inform the pilot* […]".

The following details are contained in the skydiving club's Flight Operations Manual in relation to these requirements:

"*The jumpmaster will ensure that all persons on board are secured with the restraining straps provided, and will inform the pilot when all are secure. Above 1000 ft AGL* [Above Ground Level] *the pilot will inform the persons on board to release and safely stow the restraining straps*".

1.14.1.6 UK CAA Guidance Material

G-SKYE is a UK-registered aircraft and as such, when operated in the UK, it was required to be operated in accordance with CAA guidelines as well as European Legislation. In July 2008, the UK CAA published CAP (Civil Aviation Publication) 660, entitled, '*Parachuting*', from which the IAA guidance material was derived (**Section 1.14.1.2**). In the CAA document, parachute operations for reward are also classified as "*Aerial Work*". There is no stated requirement in the CAA guidance material for restraints to be fitted to all aircraft involved in parachute operations.

1.14.1.7 British Parachute Association

The British Parachute Association (BPA) is the governing body for sport parachuting in the UK. All parachuting clubs affiliated to the BPA must operate in accordance with the conditions laid down in their Operations Manual. It is stated in Section 1.9 of the Manual that "*Where parachutists' restraints are fitted, they are to be used during take-off and landing*". However, there is no stated requirement in the BPA's Operations Manual for restraints to be fitted to all aircraft involved in parachute operations.

1.14.1.8 Legislation Applicable in the United States

In the United States, the FAA's Code of Federal Regulations (CFR) Part 91, relates to '*General Operating and Flight Rules*'. Sub part B, Section 91.107, describes the requirements regarding the use of safety belts, shoulder harnesses, and child restraint systems. It states that "*except as provided in this paragraph*[23]*, each person on board a U.S.-registered civil aircraft* […] *must occupy an approved seat or berth with a safety belt and, if installed, shoulder harness, properly secured about him or her during movement on the surface, take-off, and landing*". One of the exceptions allowed is that a person "*may use the floor of the aircraft as a seat, provided that the person is on board for the purpose of engaging in sport parachuting*". This regulation is referred to in the FAA's Advisory Circular on Sports Parachuting, AC-105-2E, which states in paragraph 8, "*Pilot Responsibilities*", that "*in all cases, each person must have access to an installation-approved seat belt*".

1.14.1.9 Legislation Applicable in Canada

Section 605.25 of the Canadian Aviation Regulations deals with the use of '*Safety Belts and Restraint Systems*'. Sub-section (1) states that "*The pilot-in-command of an aircraft shall direct all of the persons on board the aircraft to fasten safety belts (a) during movement of the aircraft on the surface; (b) during take-off and landing* […]". Paragraph (2) states that "*The directions referred to in subsection (1) also apply to the use of the following restraint systems; (a) a child restraint system; (b) a restraint system used by a person who is engaged in parachute descents;* […]".

1.14.2 Other Accidents involving Parachute Operations Aircraft and Related Information

Internationally, a number of other accidents have occurred involving parachute operations aircraft, with unrestrained parachutists still on board. The associated investigation reports highlighted that injuries could have been prevented or reduced if restraint devices had been used and that restraint devices could also prevent inadvertent changes to the aircraft's centre of gravity as a result of occupants sliding in the aircraft cabin during aircraft manoeuvring. However, it was also highlighted that the installation of restraint devices, particularly on smaller aircraft types, can result in snagging hazards which could cause a premature release of a parachute or a 'hang-up' when a parachutist exits the aircraft.

In 2008, the NTSB produced a '*Special Investigation Report*' on the '*Safety of Parachute Jump Operations*'. The report highlighted the large number of parachutist fatalities as a result of accidents involving parachute operations aircraft. Recommendations arising from NTSB investigations were made to the FAA's Civil Aeromedical Institute (CAMI) to conduct research and testing of restraint devices capable of providing adequate protection to parachutists in the event of an accident. The results of the testing found, *inter-alia*, that dual-point restraints were superior to single-point restraints and that it was not possible to provide the same level of protection for floor seated parachutists that is afforded to occupants in seats. The FAA's Advisory Circular, 105-2C, '*Sport Parachute Jumping*' extant at the time was revised to include information on restraint devices.

[23] The exemption specified relates to the restraint of infants.

A recommendation that arose from one of the other investigations related to the most appropriate bracing position to be used by parachutists if they were on board the aircraft during an emergency landing.

Further information in relation to other accidents involving parachute operations aircraft is included in **Appendix D**.

2. ANALYSIS

2.1 Forced Landing

Following the reduction in engine power, the pilot made the timely decision to carry out a forced landing in a nearby field. The Investigation's survey of the aircraft and accident site indicated that on landing, the aircraft's energy dissipated gradually. This was likely due to the firm but obstruction-free surface of the field, the initial bounce, and the collapse of the nose landing gear when the aircraft touched back down for the second time. The collapse of the nose landing gear caused the nose of the aircraft to dig into the ground, but did not prevent it from continuing to move forward and likely resulted in a gradual deceleration. Although the left hand wing tip contacted the ground during the latter stage of the landing, it did not dig in and the aircraft returned to wings level before it came to a stop.

Forced landings as a result of a loss of engine power or other unanticipated event are not always successful and can result in injuries or even fatalities. In this accident, the injuries sustained were minor. However, except for the Pilot, none of the occupants were secured in the aircraft by means of a seat belt or restraint device and as is normal for parachute operations involving small aircraft such as the Cessna 206, the parachutists were seated on the floor. If the forced landing was not performed as well as it was in this case or if the subsequent energy had not been able to dissipate as gradually as it did, the outcome could have been much worse, as highlighted in the numerous accident investigations outlined in this Report.

2.2 Engine Failure

2.2.1 General

The Pilot reported that a "*knock*" was felt shortly after take-off from EIAB and that the engine suffered a reduction in power, but continued to run. Disassembly of the engine revealed that the crankshaft had failed at the number three main bearing journal, forward of the number six cheek (web). The mechanical damage to the fracture faces of the crankshaft and to the crankcase at the number three main bearing housing/saddle area indicate that the engine continued to run following the failure of the crankshaft.

The overhaul of the engine as fitted to G-SKYE was certified in July 2009 by an MRO approved by the UK CAA in accordance with EASA Part 145. The 'bottom end' used during the overhaul of the engine was overhauled by the same MRO in August 2003. Records indicate that it contained a new crankshaft which was manufactured in March 2003.

The overhauled ‘bottom end’ remained in storage from 2003 until it was used during the overhaul of G-SKYE’s engine in 2009. Records also indicate that the ‘bottom end’ was corrosion inhibited every three months while in storage.

Due to anomalies in the aircraft records, it was not possible to determine the exact date that the overhauled engine was fitted to the aircraft, which was either in mid-2009 or early 2010. However, the records indicated that the engine had operated for less than 100 hours since overhaul before the crankshaft failed.

The ADs relating to crankshafts on the engine type fitted to G-SKYE (TSIO-520) were reviewed and found not to be applicable in this case. One of these ADs, FAA AD 2000-23-21, required a core sample to be taken from the area of the propeller flange of certain crankshafts. Although this AD was not applicable to the crankshaft found fitted to the engine on G-SKYE, the crankshaft bore evidence of a core sample being removed from the propeller flange area. However, this had no effect on the crankshaft failure.

AD 2009-16-03 and AD 2014-05-29 had not been complied with on G-SKYE. These ADs related to the engine cylinders and were not connected with the crankshaft failure.

Except for the replacement of the turbocharger and associated waste-gate in November 2013 and the performance of scheduled maintenance, the log books indicated that no other engine work was performed since overhaul. It was reported by the MRO, where the turbocharger and waste-gate were replaced, that they were fitted in accordance with the Maintenance Manual. It was also stated that ground runs were carried out to ensure maximum boost pressure was not exceeded and that fuel flows were correct. Therefore, the replacement of the turbocharger and waste-gate is not considered to be a factor in the failure of the crankshaft.

2.2.2 Metallurgical Analysis of Fractured Crankshaft

Detailed analysis of the crankshaft revealed no pre-existing defects within the core material or associated metallurgical treatments.

Significant smearing and adhesion of material were found on the surface of the fractured number three main journal, which were deemed likely to be associated with the break-up of the main bearing. The presence of this material is also evidenced by the increased diameter of the journal when compared with the other three main journals. The smearing and adhesion indicate that metal to metal contact between the number three main bearing and the number three journal occurred, which would result in localised heating of the journal. Localised heating is evidenced by the visible heat tinting present and by the formation of a transformed layer in the micro-structure of the crankshaft material near the journal surface. This localised heating adversely affected the case hardening (nitriding) and the strength of the journal and resulted in thermal expansion of the journal. The brittle longitudinal cracking present on the journal surface is believed to be a consequence of this thermal expansion. Metallurgical analysis identified that the longitudinal surface cracks initiated a number of fatigue cracks which propagated through the wall thickness of the journal, resulting in final fracture of the crankshaft.

2.2.3 Lubrication of Main Bearings

Oil, under pressure, is supplied to each main bearing through a gallery which lines up with a hole in the bearing shell. The bearings are prevented from rotating by the clamping action of the crankcase halves (bearing crush) and by the presence of a lug/tang on each bearing shell. Metal to metal contact between the rotating crankshaft and a main bearing is normally prevented by hydrodynamic lubrication, which relies on an unrestricted flow of oil from the gallery and through the hole in each bearing shell.

The crankcase oil galleries were found to be clear of obstructions. The oil pump inlet strainer was present and records indicate that the engine oil filter was replaced during the 50 hour inspection carried out approximately 18 hours prior to the accident. The traces of metallic debris observed in the oil pump during engine disassembly were likely drawn through the inlet strainer as the failure sequence developed. Apart from the number three main bearing, all other crankshaft bearings were intact and except for the damage to the number three main journal, there was no evidence of excessive wear on the other journals. It is therefore likely that pressurised lubricating oil was available for each of the main bearings. However, if a bearing shell rotates or shifts in its housing/saddle, its lubrication hole will no longer align with the gallery in the crankcase and the flow of pressurised oil into the bearing will be adversely affected. This would lead to smearing, adhesion and overheating due to metal to metal contact between the journal and the bearing.

2.2.4 Unapproved Sealant

As part of the normal investigation process, the Engine Manufacturer was advised of the accident. When it was realised that the crankshaft had broken, the Investigation provided an update to the Engine Manufacturer and other interested parties. An investigator employed by the Engine Manufacturer advised that this type of engine failure can be caused by the presence of a sealant on the "*case mating surfaces*" as it "*does not allow a solid fit between the case halves and allows movement*". This information was provided before engine disassembly was complete, and before the Engine Manufacturer was informed of the presence of a white-coloured sealant on the crankcase parting surfaces. The use of incorrect sealant has been identified as a factor in several other engine failures.

Subsequent engine disassembly revealed the presence of a white-coloured sealant on the crankcase parting surfaces. No major engine work was recorded in the engine log book since overhaul and it is likely that the white-coloured sealant was applied in 2003 during the overhaul of the 'bottom end' that was used for the overhaul of G-SKYE's engine in 2009. The sealant was analysed as part of the Investigation and was identified as likely to be RTV-102. This sealant is not approved by the Engine Manufacturer for use on the crankcase parting surfaces of its engines. The MRO where the engine and 'bottom end' were overhauled was informed of this finding. However, they reported that they do not use RTV-102 during the overhaul of TCM engines.

The tack-free time of RTV-102 is stated to be 20 minutes. If this sealant is used during overhaul on the crankcase halves of TCM engines, it may have already started to cure before the crankcase through-bolts are correctly torqued and could adversely affect the integrity of the joint formed. The correct process on TCM engines is to use '*Permatex 3D'* and silk thread. According to the Manufacturer, the Permatex is only used to hold the silk thread in place; the silk thread performs the actual sealing function.

2.2.5 Failure Sequence

Several possibilities were considered regarding the crankshaft failure sequence.

2.2.5.1 Bearing Movement due to Engine Overhaul

The 'bottom end' of the engine fitted to G-SKYE was overhauled in 2003. It is possible that a bearing was misaligned during the assembly of the crankcase halves when the 'bottom end' was overhauled, although the bearing tangs would normally prevent such a misalignment.

This 'bottom end' was placed in storage for a number of years before being used for the overhaul of G-SKYE's engine in 2009. In order to fit the cylinders to an overhauled 'bottom end', the 'slave nuts' used to temporarily secure the crankcase halves would normally be sequentially removed, to allow each cylinder to be fitted with the correct nuts. There is a potential for a main bearing to be disturbed during this process. Furthermore, the through-bolts must be torqued on both sides of the engine. The Manufacturer warns that if this is not done correctly it *can "result in a loss of main bearing crush* [nip] *with main bearing shift and subsequent engine failure"*. However, the engine overhauler advised that fasteners are torqued at "*all positions on both sides of the engine at all times*" and are "*dual inspected*". The through-bolts appeared to be correctly torqued when the engine was disassembled by the Investigation.

2.2.5.2 Fretting since Overhaul leading to Bearing Rotation/Movement

The Investigation provided a copy of the metallurgical report to the Engine Manufacturer. Following a review of this report, the Manufacturer's metallurgist stated that the crankshaft failure was likely due to bearing shift as a result of a lack of torque on the crankcase through-bolts. As noted above, the through-bolts were examined during engine disassembly and they appeared to be correctly torqued. Notwithstanding this, it is possible, as previously indicated by the Engine Manufacturer, that the presence of an unapproved sealant on the crankcase parting surfaces resulted in movement/vibration between the crankcase halves and consequently at the main bearing housing/saddle mating faces.

Detailed examination of the crankcase halves was carried out to ascertain if the diameters of the crankcase main bearing housings/saddles had been reduced by fretting since overhaul. The results obtained showed that, although the diameter of the number five main bearing housing/saddle was larger than the diameter recorded in the work pack for the bottom-end overhaul, the diameters of the three other saddles measured were found to be less than the figures recorded in the work pack (**Section 1.12.6** and **Appendix A, Table No. A4** refer).

The work pack for the overhaul of the 'bottom end' refers to the condition of the main bearing housings/saddles and the crankcase joint faces as being "*satisfactory*", which does not preclude the possibility that some minor fretting damage was present at engine overhaul. Nevertheless, the significant fretting damage observed on the crankcase parting surfaces and on the mating surfaces of the bearing housings/saddles, in addition to the indentations on the bearing saddle faces caused by the tangs of the bearings in the opposite saddles and the reduction in the bearing housing/saddle diameters noted as outlined above, indicate that vibration/movement had occurred since overhaul. This could lead to bearing shift.

2.2.5.3 Fretting since Overhaul leading to a Reduction in Clearance between the Main Bearings and Main Journals

A certain amount of clearance between a journal and its bearing, as specified by the Engine Manufacturer, is necessary to allow for correct lubrication. It is possible that a reduction of the internal diameter of the bearing housing due to fretting could lead to a corresponding reduction in the clearance between the main bearings and journals. This could adversely affect the hydrodynamic lubrication of the main journals, leading to excessive wear. The diameters of the main journals were found to be less than the Manufacturer's in-service limit. Although visual examination of the journals during metallurgical analysis revealed the presence of some circumferential scoring, no evidence of thermal distress or excessive localised wear was found on the number one, two or four main journals.

2.2.5.4 Lack of Engine Preservation during Periods of Inactivity

Records indicate that the aircraft was not operated for extensive time periods, yet there was no documented record of engine or aircraft preservation/corrosion inhibition actions taken prior to the periods of inactivity. According to the Engine Manufacturer's SIL 99-1, "*corrosive attack can occur in engines that are flown only occasionally* […]". It is essential therefore that the Manufacturer's recommended preservation actions are complied with. However, in this case, there was no corrosion found on the crankshaft. In addition, there was no evidence of corrosion on the number one, two, four and five main bearings or on the rod (big-end) bearings. The diameters of five of the six rod journals were found to be less than the in-service limit. However, as with the main journals no evidence of corrosion, thermal distress or excessive localised wear was found.

2.2.5.5 Failure Summary

The Investigation considers it is most likely that the metal to metal contact identified during metallurgical analysis of the broken crankshaft occurred as a result of obstructed oil flow, due to bearing shift. It is not possible to definitively establish the cause of the bearing shift.

The bearing shift may have been caused during 'bottom end' overhaul or subsequent engine assembly. It may also have occurred as a result of movement between the crankcase halves during engine operation as indicated by the fretting marks observed. The presence of the incorrect sealant may have been a factor in this movement, as the Engine Manufacturer stated that the use of unapproved sealant was identified as a factor in several other crankshaft failure events. In this case, unapproved sealant was only found on the crankcase parting surfaces and on the lower mating faces of the camshaft supports; in other similar failures, sealant was also found on the bearing housing/saddle mating faces.

Instructions on the use of the correct sealant and application process for the crankcase halves are contained in the engine overhaul manual. Furthermore, the Engine Manufacturer published a Service Information Letter in 1999 (99-2), which contained a list of the sealants that were approved for use on its engines. Application diagrams were also included which highlighted where on the crankcase parting surfaces the sealant and silk thread were to be applied. The latest revision of this SIL (99-2C) was published in September 2014 and now contains enhanced sealant and silk thread application diagrams. The diagrams include colour coding to indicate where the sealant and thread is required and where it is prohibited. These instructions are clear, however, the Investigation considers that the publication and promulgation of additional information to a wider group in the form of publications such as the FAA's Special Airworthiness Information Bulletin and EASA's Safety Information Bulletin would further highlight the importance of using the correct sealant/process during engine overhaul. Accordingly, the following Safety Recommendations are made:

Safety Recommendation No. 1

The United States Federal Aviation Administration should consider issuing a Special Airworthiness Information Bulletin highlighting the importance of using the correct sealant/process on the crankcase parting surfaces of engines manufactured by Teledyne Continental Motors **(IRLD2015010)**.

Safety Recommendation No. 2

The European Aviation Safety Agency should consider issuing a Safety Information Bulletin highlighting the importance of using the correct sealant/process on the crankcase parting surfaces of engines manufactured by Teledyne Continental Motors **(IRLD2015011)**.

2.3 Safety Restraints for Parachutists

2.3.1 Legislation and Guidance Material

Within Europe, EASA is responsible for promoting common standards of safety and environmental protection in civil aviation and assists in the development of EU Regulations pertaining to aviation. At the time of the accident, Regulation (EU) No 859/2008 (EU-OPS) was in force. This Regulation contained requirements pertaining to the installation and use of seat belts and harnesses on aircraft being used for commercial air transport. It was specifically stated in the Regulation that it did not apply to "*parachute dropping flights*".

In the cases of Ireland and the UK, specific requirements for parachute operations are contained in the guidance material produced by the IAA and the CAA and in the Operations Manuals of the PAI and the BPA. However, there are differences in the requirements of the two associations. In particular, the requirement of the PAI (which resulted from an IAA stipulation) to "*ensure all parachutists on-board have seat belts securely fitted*" is not replicated by the BPA.

There are also differing requirements for restraint of parachutists in other jurisdictions. In Canada, it is a requirement that parachutists are restrained during take-off and landing or at any time during flight that the pilot-in-command deems it necessary. Similarly, in the United States, it is a requirement that each person on board a U.S. civil-registered aircraft (including parachutists) must be secured with a seat belt or harness during movement on the surface or during take-off or landing. Other states, such as New Zealand do not mandate the installation of restraints due to concerns regarding the possibility of entanglement or premature parachute deployment when exiting the aircraft for a jump. Similar concerns were voiced in the UK by the BPA in their response to the AAIB recommendation relating to the installation of restraint devices on parachute operations aircraft.

The studies conducted by the United States FAA showed that sitting on the floor of an aircraft involved in parachute operations does not offer the same protection as that provided to seated passengers. It was also highlighted in the studies that dual-point restraint systems were superior to single-point restraints and that single-point restraints were not recommended in certain situations. Further to this study, the NTSB noted that the best method for restraint will vary depending on the aircraft type and its configuration and consequently recommended further research. According to the NTSB, a follow-up report on this research does not appear to have been published. However, the FAA did revise their Advisory Circular on Sports Parachuting to include guidance on the use of restraints in parachute operations aircraft. In this Circular, various seating configurations are considered. For parachutists seated on the floor facing rearwards, as noted during the studies, the document states that "*dual point, dual tether restraints offer superior restraint compared to single point, single tether restraints*" and that "*single point, single tether restraints are not recommended*".

As highlighted by the numerous accidents discussed in this Report, if parachutists are not appropriately restrained during take-off, there is potential for serious injury or death when an unanticipated event such as a rejected take-off or forced landing occurs. Parachutists are normally not on board for the landing phase and similar risks may also exist if they remain on board, for whatever reason, for a normal landing and are not restrained. In addition, for larger aircraft types, there may be a risk of unrestrained parachutists inadvertently moving during take-off and hence adversely affecting the aircraft's centre of gravity.

New European regulations regarding aircraft operation have been developed, specifically Regulation (EU) 379/2014 (Specialised Operations – SPO) which amends Regulation 965/2012. States had the option of not implementing Regulation 379/2014 until 2017 and Ireland chose this option. '*Section SPO.GEN.106 (b*)' of Regulation 379/2014, when implemented, requires task specialists, including parachutists, to be restrained at their assigned station during critical phases of flight or whenever deemed necessary by the pilot-in-command in the interests of safety. Section '*SPO.SPEC.PAR.110 Seats*' (Annex VIII, sub part E) states that "*the floor of the aircraft may be used as a seat, provided means are available for the task specialist to hold or strap on*" (See **Appendix B**).

The possible conflicting requirements of safe egress during normal parachute operations versus effective restraint during abnormal situations such as a rejected take-off or a forced landing require careful consideration to ensure that safety is optimised in both situations. Section '*SPO.SPEC.PAR.110 Seats*' (Annex VIII, sub part E) of Regulation (EU) No 379/2014, which was not in force at the time of the accident, appears to permit parachutists to either be restrained or to have something to hold onto as outlined above. The Investigation considers that a 'hold-on' device is not an adequate means of restraint. Furthermore, Certification Specification CS 23 and the Special Condition document relating to the use of aircraft for parachuting operations (SC-023-div-01) do not contain technical requirements for restraint devices. The Investigation is of the opinion that further research similar to that conducted by the FAA, on the most appropriate means of restraint, including if required, differing requirements specific to aircraft size, could result in safety improvements for parachute operations throughout Member States. This research could be used in the development of future legislation and guidance material. Consequently, the Investigation makes the following Safety Recommendation to EASA:

Safety Recommendation No. 3

The European Aviation Safety Agency should conduct a safety study in relation to the most effective method of occupant restraint in aircraft engaged in parachute operations and consider whether the applicable EU Regulations and Certification Specifications adequately address the safety restraint of parachutists **(IRLD2015012)**.

2.3.2 Requirements within Ireland

The IAA issued a letter to the Irish-based skydiving club in 2010, which referred to the requirements of Regulation (EU) No 859/2008 and required that restraint devices be fitted to aircraft operated by the club. As a consequence of the IAA's letter, the aircraft normally operated by the Irish-based skydiving club, a Cessna 185 (See **Section 1.14.2**), was fitted with restraint belts for use by parachutists. The IAA informed the Investigation that similar letters were also issued to other skydiving/parachuting clubs within Ireland.

The IAA, in its guidance material for parachute operations, entitled '*Parachuting*', defines such operations for reward as "*aerial work*" and it is specifically stated in Regulation (EU) No 859/2008 (EU-OPS) that the regulation does not apply to "*parachute dropping flights*" or for flights connected with "*aerial work*" activity. The IAA's letter was issued due to concerns "*for the safety of the parachutists on board*". The subject accident and the events referred to in this Report indicate that these concerns are valid. The IAA has the power to make orders and regulations relating to aviation within Ireland. However, the Investigation notes that the European legislation referred to in the IAA's letter was not applicable to parachute operations and did not require the use of restraint devices on parachute operations aircraft.

The Permission issued by the IAA allowing the Irish-based skydiving club to conduct parachute operations required the club to comply with the relevant provisions of its (the club's) Flight Operations Manual. Because the club was affiliated to the PAI, it also operated under the PAI's Manual, which required the "*Jumpmaster*" to *"ensure all parachutists on-board have seat belts securely fitted* […]*"* and to *"ensure all seat belts are removed and safely stowed at the recommended height for the aircraft type and inform the pilot".* In the case of G-SKYE, it was not a requirement of the UK CAA, within whose jurisdiction the aircraft normally operated, that the aircraft be fitted with restraints for use by each parachutist carried. The Irish-based Lessee stated that he only became aware that the aircraft was not fitted with restraint devices following its arrival in Ireland and thought that as the aircraft was controlled by the UK CAA, "*they* [the CAA] *were happy with the configuration of the aircraft*". Furthermore, the IAA had amended '*Schedule 1*' of the skydiving club's permission certificate to include G-SKYE. The Lessee discussed the lack of restraint devices with the club's tandem masters and as the aircraft was leased on a temporary basis, it was used by the club in the configuration that it arrived in.

2.3.3 Brace Position

No significant injuries occurred as a result of the forced landing on G-SKYE. However, during the course of this Investigation, it was noted that neither the PAI Operations Manual nor the skydiving club's Flight Operations Manual contained guidance on a suitable bracing position to be adapted by occupants during a forced landing. European legislation in force at the time of the subject event and the new European legislation yet to be implemented do not include such a requirement.

Since the subject event, the IAA has published an '*Operations Advisory Memorandum*' (No. 2/15), which contains information for persons engaged in parachute jumping in Ireland. It states that "*the aircraft operator and the Pilot in Command are responsible to ensure that Task Specialists are appropriately briefed and understand their role in the aircraft operation and any associated risks, particularly in the event of an on-board emergency or an emergency landing*".

The most appropriate bracing position to use in the event of an emergency landing would depend upon the normal seating positions adopted on board a parachute operations aircraft and would therefore be specific to each aircraft. The Investigation considers that if appropriate bracing positions were developed and parachutists were briefed before departure on the bracing position relevant to their seating position, the potential for injury during a forced landing may be reduced. The Investigation therefore makes a Safety Recommendation to the EASA in this regard.

Safety Recommendation No. 4

The European Aviation Safety Agency should consider developing requirements for appropriate bracing positions to be identified for each occupant position on aircraft engaged in parachute operations and that these positions be highlighted to occupants at an appropriate time such as during pre-flight briefings **(IRLD2015013)**.

2.3.4 Aircraft Configuration

G-SKYE was operated with the right hand cockpit seat removed and with a wooden structure covering the right hand foot well and rudder pedals (See **Section 1.10.1, Photo No. 2**). The Tandem Master who was sitting with his back to the wooden structure was a very experienced parachutist and advised the Investigation that when he became aware that a forced landing was necessary, he realised that the control column/wheel would be obstructed by his head when the Pilot moved it rearward to flare the aircraft. If this occurred, it could have impeded the Pilot's ability to control the aircraft during the forced landing. To prevent this from occurring, the Tandem Master slid down to allow the control column/wheel to pass over his head. During the forced landing he then hit his head off the extended control column/wheel.

The aircraft was approved for parachute operations by the UK CAA by way of a supplement to the Pilot's Operating Handbook (Supplement 3, Issue 5, dated 16 June 1995). In addition, it was indicated on the Airworthiness Review Report completed by a CAA approved CAMO during the renewal of the ARC, that the aircraft in its current configuration complied with the type design certification and that all modifications had been approved in accordance with EASA Part 21. The modification to convert the aircraft to parachute operations did not include protection of the control column to ensure its full and free movement at all times. The Investigation considers that the approval of similarly modified aircraft should be reviewed to ensure that the risk of control column/wheel obstruction by parachutists is eliminated. Consequently, the following Safety Recommendation is made to the UK CAA:

Safety Recommendation No. 5

The UK Civil Aviation Authority should ensure that the risk of cockpit control obstruction is considered during aircraft inspections performed on UK-registered parachute operations aircraft prior to the issue of airworthiness certification **(IRLD2015014)**.

It should be noted that such a requirement forms part of EASA's '*Special Condition*' document (SC-023-div-01) which applies to applications for EASA approval made after 6 July 2009.

3. CONCLUSIONS

(a) Findings

1. The aircraft was operating on a valid Airworthiness Review Certificate.

2. Records indicate that the most recent Annual Maintenance Inspection was carried out on the aircraft on 5 November 2013 and a 50 hour Maintenance Inspection was carried out on 12 May 2014 as required.

3. The aircraft was not flown for extensive time periods, yet there was no documented record of engine or aircraft preservation actions taken prior to the periods of inactivity.

4. The skydiving club was engaged in parachute operations under a Permission Certificate issued by the IAA.

5. The aircraft was listed on the IAA Permission Certificate.

6. The Pilot's licence and medical certificate were valid.

7. The aircraft took off from EIAB with the Pilot, two Tandem Masters and two persons skydiving for charity on board.

8. The two Tandem Masters on board at the time were listed on the Permission Certificate.

9. Shortly after take-off, the aircraft's engine suffered a reduction in power. Following the reduction in engine power, the Pilot performed a forced landing in a field 1.6 NM west northwest of EIAB.

10. The aircraft sustained substantial damage as a result of the forced landing.

11. Except for the Pilot's seat harness, there was no provision for restraint of the occupants in the aircraft's parachute operations configuration.

12. The occupants were able to promptly exit the aircraft.

13. There were no significant injuries reported to the Investigation.

14. In 2010, the IAA issued a letter to the skydiving club requiring that restraint devices be fitted to the aircraft normally operated by the club.

15. The European legislation referred to in the IAA's letter requiring that restraint devices be fitted was not applicable to parachute operations.

16. The aircraft had been leased from the UK approximately three weeks before the accident.

17. There is no requirement within the UK for restraint devices to be fitted to parachute operation aircraft.

18. At the time of the accident there was no EASA requirement for restraint devices to be fitted to parachute operations aircraft.

19. The engine had been released from overhaul in July 2009. The ‘bottom end’ used during the overhaul of the engine was overhauled in 2003 and was not used until 2009. Records indicate that it was corrosion inhibited every three months while in storage.

20. Records indicate that the engine operated for approximately 98 hours since overhaul.

21. The engine power reduction was a result of a broken crankshaft, which fractured between the number three main journal and the number six cheek/web.

22. The fracture was caused by localised overheating and associated thermal expansion, due to metal to metal contact between the number three main journal and the number three main bearing.

23. The metal to metal contact is likely to have occurred as a result of a loss of lubrication due to a misalignment between the oil supply port in the crankcase and the oil supply hole in the bearing caused by main bearing shift.

24. During engine disassembly, a white-coloured sealant was found on the crankcase parting surfaces.

25. This sealant was identified as likely to be RTV-102, which is not approved by the Engine Manufacturer for use on this engine type.

26. The use of unapproved sealants was identified as a factor in other crankshaft failure events on TCM 520 series engines. However, in these other events, the sealant was applied to the mating faces of the bearing housings/saddles. In the case of G-SKYE, the white-coloured sealant was not found on the mating faces of the bearing housings/saddles.

(b) Probable Cause

A forced landing due to a loss of engine power, attributable to a fatigue failure of the crankshaft at the number three main journal.

(c) Contributory Factors

A loss of lubrication at the number three main bearing resulting in metal to metal contact between the bearing and the journal.

4. SAFETY RECOMMENDATIONS

	It is Recommended that:	Recommendation Ref.
1.	The United States Federal Aviation Administration should consider issuing a Special Airworthiness Information Bulletin highlighting the importance of using the correct sealant/process on the crankcase parting surfaces of engines manufactured by Teledyne Continental Motors.	IRLD2015010
2.	The European Aviation Safety Agency should consider issuing a Safety Information Bulletin highlighting the importance of using the correct sealant/process on the crankcase parting surfaces of engines manufactured by Teledyne Continental Motors.	IRLD2015011
3.	The European Aviation Safety Agency should conduct a safety study in relation to the most effective method of occupant restraint in aircraft engaged in parachute operations and consider whether the applicable EU Regulations and Certification Specifications adequately address the safety restraint of parachutists.	IRLD2015012
4.	The European Aviation Safety Agency should consider developing requirements for appropriate bracing positions to be identified for each occupant position on aircraft engaged in parachute operations and that these positions be highlighted to occupants at an appropriate time such as during pre-flight briefings.	IRLD2015013
5.	The UK Civil Aviation Authority should ensure that the risk of cockpit control obstruction is considered during aircraft inspections performed on UK-registered parachute operations aircraft prior to the issue of airworthiness certification.	IRLD2015014

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Appendix A

Engine Dimensional Data

	No. 1	No. 2	No. 3 (Fractured)	No. 4
Average as Measured by Metallurgist	60.12 mm (2.3669 inches)	60.13 mm (2.3673 inches)	60.31 mm (2.3744 inches)	60.15 mm (2.3681 inches)
As Recorded at Overhaul	2.3745 inches	2.3745 inches	2.3745 inches	2.3745 inches
Limits for New Crankshaft	2.3740 to 2.3750 inches			
In-Service Limit	2.3720 inches			

Table No. A1: Diameter of crankshaft main journals (Red = below Overhaul Manual in-service limits).

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Average as Measured by Metallurgist	57.03 mm (2.2453 inches)	57.07 mm (2.2469 inches)	57.03 mm (2.2453 inches)	57.09 mm (2.2476 inches)	57.01 mm (2.2445 inches)	57.07 mm (2.2469 inches)
As Recorded at Overhaul	2.2495 inches	2.2495 inches	2.2495 inches	2.2495 inches	2.2495 inches	2.2495 inches
Limits for New Crankshaft	2.2490 to 2.2500 inches					
In-Service Limit	2.2470 inches					

Table No. A2: Diameter of rod (big-end) journals (Red = below Overhaul Manual in-service limits).

Position	Main Journal Outside Diameter (Ref Table No. A1)	Main Bearing Internal Diameter	Clearance
No. 1	2.3745	2.3765	0.0020
No. 2	2.3745	2.3770	0.0025
No. 3	2.3745	2.3765	0.0020
No. 4	2.3745	2.3770	0.0025
No. 5	2.3745	2.3775	0.0030

Table No. A3: Main bearing clearances (inches) as recorded in work pack for engine overhaul. The engine overhaul manual limits referred to in the work pack were 0.0005 to 0.0035 inches for new parts, with the in-service limit stated to be 0.005 inches. **Note**: The Engine Manufacturer advised that for this particular crankcase, the correct limits are 0.0018 to 0.0047 inches. However, the clearances recorded by the engine overhauler are within these limits.

	No. 1 Main Bearing Bore (Inches)	No. 2 Main Bearing Bore (Inches)	No. 3 Main Bearing Bore (Inches)	No. 4 Main Bearing Bore (Inches)	No. 5 Main Bearing Bore (Inches)
A	2.5625	2.5620		2.5625	2.5645
B	2.5615	2.5615		2.5620	2.5610
C	2.5645	2.5635		2.5620	2.5650
Average of A, B and C	2.5628	2.2623		2.5622	2.5635
Dimension Recorded at Overhaul	2.5635	2.5625	2.5620	2.5625	2.5625
Difference*	0.0007	0.0002		0.0003	+0.0010

Table No. A4: Internal diameter of main bearing housing/saddles (without bearings fitted). Measurements taken at three locations in each bore A, B and C. (***** Difference between dimension recorded at engine overhaul and average of measurements obtained).

Appendix B

Extracts from Regulation (EU) No 379/2014 and Associated Information

Regulation (EU) No 379/2014 Section '*SPO.IDE.A.160 Seats, seat safety belts and restraint systems*' (Annex VIII, sub part D) states, *inter-alia*: "*Aeroplanes shall be equipped with: (a) a seat or station for each crew member or task specialist on board; (b) a seat belt on each seat, and restraint devices for each station* […].". Note: A task specialist is defined in Regulation (EU) No 379/2014 as "*a person assigned by the operator or a third party, or acting as an undertaking, who performs tasks on the ground directly associated with a specialised task or performs specialised tasks on board or from the aircraft".*

Section *SPO.GEN.106 (b)* of sub part A of Annex VIII *(Task specialists responsibilities)*, states that: "*Except for balloons, during critical phases of flight or whenever deemed necessary by the pilot-in-command in the interest of safety, the task specialist shall be restrained at his/her assigned station unless otherwise specified in the SOP* [Standard Operating Procedure]" and in paragraph (c) that "*the task specialist shall ensure that he/she is restrained when carrying out specialised tasks with external doors opened or removed"*.

Section three of sub part E of Annex VIII, ('*Specific Requirements*') deals with '*Parachute Operations*' (PAR). Within this section, '*SPO.SPEC.PAR.105 Carriage of crew members and task specialists*' states "*the requirement for task specialist's responsibilities as laid down in SPO.GEN.106 (c)* [Annex VIII, sub part A, as outlined above] *shall not be applicable for task specialists performing parachute jumping*".

Section, 'SPO.SPEC.PAR.110 Seats' (Annex VIII, sub part E), it is stated that "*the floor of the aircraft may be used as a seat, provided means are available for the task specialist to hold or strap on*".

EASA '*Opinion*' documents may be utilised during the development of EU Regulations. EASA '*Opinion*' document 02/2012 was issued in April 2012 and states that "*the purpose of this Opinion is to assist the European Commission in laying down Implementing Rules for air operations*". It relates specifically to Annex VIII '*Specialised Operations*'. Section IV, paragraph 53 of the '*Opinion*' states: *"Parachute operations (PAR) contains several alleviations to the rules of Subpart A-D in order for the jumpers (in the rule referred to as task specialists) to perform their task. For instance, they need to be able to jump out of the aircraft and therefore the requirement to be restrained is not be* [sic] *applicable for them".*

Similar requirements for parachute operations are also contained in Annex VII '*Non-Commercial Air Operations with other than Complex Motor Powered Aircraft'*[24] (NCO).

[24] **Complex Motor Powered Aircraft:** A fixed-wing aircraft with a maximum certificated take-off mass exceeding 5,700 kg, or certificated for a maximum passenger seating configuration of more than nineteen, or certificated for operation with a minimum crew of at least two pilots, or equipped with (a) turbojet engine(s) or more than one turboprop engine. Certain helicopters and tilt-rotor aircraft can also be classified as Complex Motor Powered Aircraft.

Appendix C

Extract from IAA Operations Advisory Memorandum 2/15 (3 July 2015)

Aircraft Operations

European Aviation Regulations for aircraft operations regard the transport of parachutists as a specialist operation (SPO). This means that parachutists (including novice parachutists) are considered to be participants in the operation rather than passengers in the aircraft. Parachutists are considered to be ***'task specialists'*** *when they are being transported in an aircraft for the purpose of a parachute jump. The aircraft operator must assign the duties to be performed on the ground, on board and from the aircraft to each task specialist. The 'Task Specialist' is required to have specific knowledge of those duties. This is also the case when two parachutists jump using the same parachute equipment (normally referred to as a tandem jump). The EU regulations also allow aircraft operating in support of parachute dropping to use the floor of the aircraft as a seat. This is a higher level of risk than normally allowed for passengers in an aircraft on a private or commercial flight where a seat and a seatbelt must be provided. This higher level of risk assumes that the Task Specialist is aware and accepts a lower level of safety as part of their activity. The aircraft operator and the Pilot in Command are responsible to ensure that Task Specialists are appropriately briefed and understand their role in the aircraft operation and any associated risks, particularly in the event of an on-board emergency or an emergency landing.*

Appendix D

Other Accidents involving Parachute Operations Aircraft and Associated Information

D1 Other Accidents

D.1.1 Cessna U206F in Devon, UK, 27 June 2004

In this UK accident, which involved a similar aircraft type to G-SKYE, the aircraft's engine began to lose power shortly after take-off with a pilot and five parachutists on board. In an attempted forced landing, the aircraft clipped the tops of several tall trees and crashed nose-down into a sloping grass field. The Pilot and three parachutists were killed. The passenger layout was similar to that used on G-SKYE.

According to the report[25] published by the UK Air Accidents Investigation Branch (AAIB), the pilot was the only one on board who was seated and restrained. The AAIB reported that, although the impact in that case was severe, there were two survivors and thus it was a survivable accident. Regarding the restraint of occupants, the AAIB report stated: "*The lack of any restraint system in the aircraft for the parachutists is an accepted practice* [in the UK] *as it allows safe and quick egress when jumping from the aircraft without* […] *the danger of tripping or snagging equipment on any seat structures or floor attachments. However, in the case of an emergency landing, the occupants are afforded little protection from any impact forces*".

The AAIB made several Safety Recommendations, including the following (reference number 2005-045):

"*It is recommended that the British Parachute Association, in consultation with the Civil Aviation Authority, consider the practicality of installing appropriate restraint systems for parachutists in all aircraft engaged in parachuting operations*".

This recommendation was rejected by the BPA. The response to this recommendation from the BPA is contained in the AAIB's progress report on safety recommendations from 2007, which is available on their website.

In summary, the BPA responded by stating that the current requirements regarding the restraint of parachutists were developed in conjunction with the CAA and that the requirement was to comply with the relevant section of the aircraft's flight manual. It was noted that when the current requirements were developed it was agreed that restraints in smaller aircraft were problematic and should not be required. It was recognised however, that the need for restraints increased in relation to an aircraft's size due to the potential for weight shift and that these restraints would also provide some protection in the event of a crash.

[25] **Report Reference:** EW/C2004/06/02

The BPA did not dispute that in a crash situation, the chances of survivability for parachutists increased if restraints were worn. However, they noted that restraints can pose other safety risks when fitted to small aircraft, such as the Cessna 206. The rationale given was that parachutists are normally seated on the aircraft floor in close proximity to each other and are normally wearing bulky equipment and that the "*close crowding makes the wearing of restraints extremely difficult and would entail a mass of loose webbing and hardware fittings littering the cabin floor when the time comes to exit the aircraft*". The BPA stated that such a scenario presents a number of hazards to parachutists, summarised as follows:

- As they attempt to exit the aircraft from a seated or kneeling position, they risk part of their own parachute pack or harness snagging on the loose restraint straps and hardware in the aircraft. This can result in a 'hang up' scenario where a parachutist is left suspended outside the aircraft; a situation which presents very obvious dangers and difficulties.

- Premature deployment of the parachute within, or just outside the aircraft due to snagging on the loose restraint straps and hardware in the aircraft. It was noted that this danger is greater now than it was historically because old style parachute rip cord handles were usually mounted on a parachutist's chest and were within his view.

With regard to larger aircraft, the BPA noted that restraints continue to be a safety benefit as they do not present the same hazard as they would on a small aircraft.

One of the other recommendations made by the AAIB related to brace positions to be adopted by parachutists in the event of an emergency landing. It stated the following (reference number 2005-060):

"*It is recommended that the British Parachute Association, in consultation with the Civil Aviation Authority, establish an appropriate 'brace' position for each seating position on aircraft engaged in parachuting operations*".

This recommendation was made because a student tandem parachutist on board the aircraft survived the UK accident but according to the AAIB's report, could not recall any information that might have been given before take-off on the brace position to adopt in case of emergency. It was reported that one of the other parachutists on the aircraft described the brace position he was advised to adopt, which was to put his hands on his head and place his chest towards his knees. It was deemed by the AAIB that this would be a suitable brace position in a forward facing airline seat with a lap belt where the occupant is likely to be thrown forward during an impact. However, it was stated in the report that "*adopting a similar position whilst facing rearwards is probably the worst position to adopt, and is likely to result in the head and upper body being rotated backwards (towards the front of the aircraft) and being brought rapidly to a halt should they strike a fixed structure or the person behind*".

The full response to this recommendation is also contained in the AAIB's progress report from 2007. In this response, the BPA stated that following research and consultation with industry experts, it was "*unable to issue firm advice based upon empirical research* […]". Nevertheless, the BPA did prepare written advice regarding crash landing procedures which was subsequently published as an official BPA Form (261) for incorporation into the BPA Instructor Manual. It stated that an amendment was also made to the BPA's Operations Manual that "*All parachutists must have been briefed as to the emergency crash procedures and brace positions relevant to their seating or kneeling positions in the aircraft*".

Procedures in relation to the most appropriate brace position are not included in the PAI's Operations Manual or in the Irish-based skydiving club's Flight Operations Manual. This is not a requirement of European or national legislation.

D1.2 Fletcher FU24 in Fox Glacier, New Zealand, 4 September 2010

In this accident at Fox Glacier, New Zealand, the aircraft reportedly lost control and crashed shortly after take-off with one pilot and eight parachutists on board. All nine occupants were fatally injured. With the exception of the pilot, no one on board was wearing a safety restraint or belt. Regulations in New Zealand exempted passengers engaged in parachuting operations from the requirement to occupy seats and wear restraints for take-off and landing.

The associated accident investigation report[26] found that the aircraft's centre of gravity was outside the maximum aft limit, which would have caused "*serious handling issues*" leading to the aircraft becoming airborne at too low a speed to be controllable. After take-off, the aircraft continued to pitch up, then rolled left before striking the ground nearly vertically. The aircraft reached a pitch angle that would have made it "*highly improbable for the unrestrained parachutists to prevent themselves sliding back towards the tail*". It was noted that any shift in weight rearward would have made the aircraft more unstable. One of the report's findings was that "*safety harnesses or restraints would help to prevent passengers sliding rearward and altering the centre of gravity of the aircraft. It could not be established if this was a factor in this accident* [at Fox Glacier]".

The report also stated that a study of passenger restraints had recently been completed in conjunction with industry representatives. The study was recommended following a previous accident in Motueka, New Zealand, in which the pilot and five parachutists were injured. The report for the accident in Motueka noted that "*the seriousness of the injuries sustained by the occupants may have been reduced had they been wearing some form of safety restraint*". It was reported that as a result of the study, the CAA decided not to mandate the fitment of restraints to "*smaller aircraft*", typically those carrying 10 or fewer parachutists. It was stated that "*There was a continued concern that, for small aircraft in particular, parachutists could become tangled with the restraints, causing the premature release of a parachute or a hang-up on exiting the aeroplane. Both scenarios were reported to have occurred both in New Zealand and overseas*".

[26] **Report Reference:** 10-009. Approved for publication in April 2012.

It was also stated in the report that "*proper safety restraints have been shown to reduce flailing injuries and save lives in those accidents deemed survivable. However, the impact forces sustained when* [the aircraft] *struck the ground in a near-vertical angle would not have been survivable even if typical safety harnesses had been fitted and worn*".

D2 Additional Information

D2.1 Report on the Safety of Parachute Jump Operations

In 2008, the USA's National Transportation Safety Board (NTSB) produced a '*Special Investigation Report*' on the '*Safety of Parachute Jump Operations*'. In this report it is stated that the risks of parachuting are generally perceived to involve acts of jumping from the aircraft, deploying the parachute and landing, but that a review of accident reports reveals that travelling on aircraft involved in parachute operations can also present risks. It was highlighted that there have been 32 accidents in the USA since 1980 involving parachute operations aircraft which have resulted in the deaths of 172 people, most of whom were parachutists. It is also stated in the report that 11 of these 32 accidents were caused by a loss of engine power after take-off and resulted in 85 fatalities.

The NTSB report referred to an accident that occurred shortly after take-off in Perris, California on 22 April 1992, in which 16 people were killed and six seriously injured. In this event, Medical personnel from the FAA's Civil Aeromedical Institute (CAMI) determined that the parachutists' fatal injuries were the direct result of not wearing restraints. The Safety Board also found that adequate numbers of restraints were not available to accommodate all of the passengers on the accident airplane. As a result of this accident, the NTSB made a number of recommendations regarding parachutists' seating and restraints. One of these safety recommendations, A-94-16, was directed at the FAA and recommended that: "*In conjunction with industry, the United States Parachute Association* [USPA], *and the* [FAA's] *Civil Aerospace Medical Institute* [CAMI], *develop and test universal restraint systems capable of providing adequate protection to parachutists similar to that provided for seated passengers*".

D2.2 NTSB's Aircraft Accident Summary Report

One of the other accidents listed in the NTSB's Special Investigation Report was an accident involving a De Havilland DHC-6 aircraft in Sullivan, Missouri in July 2006. As a result of this accident, which also occurred shortly after take-off, the pilot and five parachutists were killed and two other parachutists were seriously injured.

The '*Aircraft Accident Summary Report*'[27] into this accident also reviewed the performance of the restraints used to secure the parachutists in the aircraft cabin. The report states that, historically, parachutists have fared poorly during aircraft accidents involving parachute operations because they do not have the crash protection provided by typical aircraft passenger seat structures and passenger seat belts. The summary report also refers to the safety recommendation (A-94-16) made as a result of the 1992 accident in Perris, California.

[27] **Report Reference:** NTSB/AAR-08/03/SUM PB2008-910403.

The NTSB's Summary Report stated that as a result of this safety recommendation, the CAMI in conjunction with the USPA and the parachute industry, performed a series of dynamic tests to evaluate various types of restraint systems and occupant orientations for parachutists and published a report[28] on its findings. It is highlighted in the NTSB's report that the FAA responded to the recommendation stating that "*the testing identified possible improvements in restraining parachutists and that it is not possible to provide the same level of protection for floor-seated parachutists that is afforded to occupants in seats*".

The Report outlined that the restraint systems evaluated included both single-point and dual-point systems intended for aft-facing, floor-seated occupants. All of the systems tested were designed to pass through the parachute harness and attach to the aircraft floor. According to the NTSB "*the results of the CAMI tests revealed that dual-point restraint systems were superior to single-point restraints* […] *the Safety Board concludes that testing could identify the best method for dual-point restraint* […] *for the configuration of other airplanes commonly used in parachute operations*".

As a result of this conclusion, the NTSB made a further recommendation[29] to the FAA to: *"Conduct research, in conjunction with the United States Parachute Association, to determine the most effective dual-point restraint systems for parachutists that reflects the various configurations used in parachute operations*" (NTSB Reference A-08-71).

The Investigation requested the NTSB to outline the current status of this recommendation. The resulting recommendation report provided by the NTSB classified the recommendation as "*Closed – Acceptable Action*". The recommendation report stated that the CAMI and the USPA will investigate improved restraint methods for parachutists in recreational parachute operations. It was also stated that revisions to the FAA's Advisory Circular, 105-2C, Sport Parachute Jumping, will be made as necessary, pending the results of the research, evaluation, and development of new restraint methods. The NTSB advised the Investigation that the CAMI appears not to have produced a further report. However, Advisory Circular 105-2D which was issued on 18 May 2011 resulted in the closing of the recommendation. It included a new appendix entitled "*Seats and Restraint Systems*". It was stated in Paragraph 3b and 3c of this appendix, for rearward-facing floor seating and for rearward-facing on a straddle bench respectively, that "*single point, single tether restraints are not very effective*". Paragraph 3d states: "*Dual point dual tether restraints offer superior restraint compared to single point single tether restraints*". The latest revision of the Advisory Circular is now 105-2E, dated December 2013. Paragraph 3b for rearward-facing floor seating now states that "*Single point, single tether restraints are not recommended*". Paragraph 3c is unchanged.

- END -

[28] **Report Reference:** "*Evaluation of Improved Restraint Systems for Sport Parachutists*", DOT/FAA/AM-98/11.
[29] **Recommendation Number:** A-08-74.

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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