Report 06-005, Gippsland Aeronautics GA8 Airvan, ZK-KLC, partial engine failure, Cook Strait, 27 November 2006

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Gippsland Aeronautics GA8 Airvan

ZK-KLC

partial engine failure

Cook Strait

27 November 2006

Abstract

On 27 November 2006, about 8 minutes after departing Wellington airport on a scheduled flight to Kaikoura with one passenger, the pilot of a Gippsland Aeronautics GA8 aircraft, registered ZK-KLC, felt the engine misfire and saw that the oil pressure had reduced. The pilot immediately returned to Wellington and made a safe landing.

The engine had major internal damage, which the evidence indicated had started with the failure of an exhaust valve tappet. The cause of the tappet failure was not determined.

A safety issue was identified with regard to the risk of ditching that was associated with over-water air transport operations with single-engine aircraft. A safety recommendation was made to the Director of Civil Aviation regarding operator compliance with life raft rules.

Gippsland Aeronautics GA8 Airvan, ZK-KLC

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Abbreviations

#	number
CAA	Civil Aviation Authority
^{o}F	degrees Fahrenheit
Gipps Aero	Gippsland Aeronautics Proprietary Limited
km	kilometre(s)
L	litre(s)
Lycoming	Textron Lycoming
mm	millimetre(s)
psi	pound(s) per square inch
RPM	revolutions per minute
Soundsair	Sounds Air Travel and Tourism Limited
UTC	coordinated universal time

Glossary

nitriding	a production treatment used to harden the surfaces of some steel alloys
spalling	surface pitting, usually caused by inadequate lubrication
spectrographic oil analysis programme	an analysis that can determine the presence and concentration, usually expressed in parts per million, of various elements. The analysis can indicate the rate of wear of certain engine components

Data Summary

Aircraft registration:	ZK-KLC
Type and serial number:	Gippsland Aeronautics GA8 Airvan, GA8-03-040
Type of engine and serial number:	Textron Lycoming IO-540-K1A5 reciprocating engine, L-29048-48A
Year of manufacture:	2003
Operator:	Sounds Air Travel and Tourism Limited (Soundsair)
Date and time:	27 November 2006, 0810[1]
Location:	approximately 15 kilometres (km) southwest of Wellington International Airport latitude: 41° 24´ south longitude: 174° 41´ east
Type of flight:	air transport operation
Persons on board:	crew: one passengers: one
Injuries:	crew: nil passengers: nil
Nature of damage:	substantial to engine
Pilot's licence:	commercial pilot licence (aeroplane)
Pilot's age:	23 years
Pilot's total flying experience:	840 hours, including 255 hours on GA8
Investigator-in-charge:	P R Williams

[1] Times in this report are New Zealand Daylight Time (UTC +13 hours) and are expressed in the 24-hour mode.

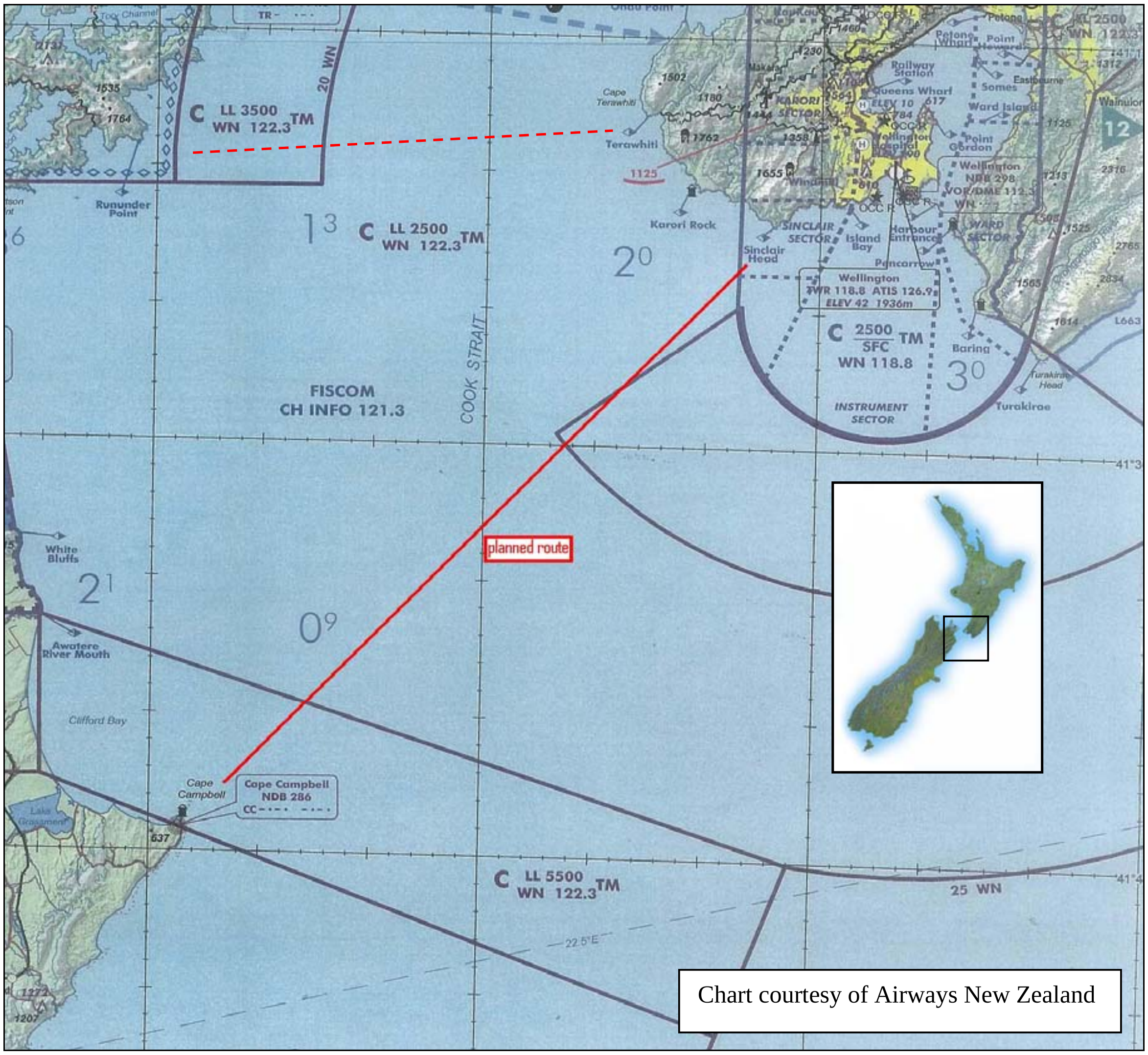

Figure 1
Planned route, Sinclair Head to Cape Campbell

1 Factual Information

1.1 History of the flight

1.1.1 On Monday 27 November 2006, a Gippsland Aeronautics Proprietary Limited (Gipps Aero) GA8 aircraft, registered ZK-KLC, was assigned to a scheduled flight under visual flight rules[2] from Wellington airport to Kaikoura, approximately 150 km to the south. The pilot gave the sole passenger a safety briefing and drew his attention to the life jacket stowage.

1.1.2 Shortly after 0800, having carried out a normal pre-flight engine run-up, the pilot performed a normal take-off using engine power settings of 2500 revolutions per minute (RPM) and about 27 inches manifold pressure. Power was reduced for the climb and at the initial cruise level of 1500 feet above mean sea level the pilot set cruise power of 2400 RPM and 24 inches.

1.1.3 The pilot had intended to cross Cook Strait from Sinclair Head directly to Cape Campbell at 3000 feet (see Figure 1) because the weather was fine. The intended route was popular for visual flights between the North and South Islands, even though it was over water for 56 km, because it was about 38 km shorter than crossing between Cape Terawhiti and Rununder Point and then following the coast to Cape Campbell. The pilot's company (the operator) had not stipulated a minimum cruise altitude for the direct route.

1.1.4 The pilot said that shortly after passing Sinclair Head, about 8 minutes after take-off, the engine "gave a kick". The only unusual engine instrument indication he could recall was the indicated oil pressure, usually steady at about 60 pounds per square inch (psi), which was fluctuating to as low as 40 psi. The oil temperature was in the green range. The passenger, who had flown with the operator before on this sector, did not notice any engine irregularity.

1.1.5 The pilot reduced power slightly and turned back towards Wellington airport. He advised air traffic control of the situation and requested priority for landing, but he did not declare any urgency[3] or request the airport rescue services to be placed on standby. For the remainder of the flight, the engine ran smoothly, but the oil pressure remained low and continued to fluctuate. The pilot landed ZK-KLC without incident, taxied to the maintenance contractor's apron and shut down.

1.1.6 The engineers had difficulty restarting the engine and abnormal resistance was encountered when turning the propeller by hand. The engine was eventually started and the oil pressure checked with a test line and found to be steady at 60 psi when at idle power. The engine oil suction screen was removed and found to be clogged with metal debris that was recognised as being from the tappets (see Figure 2). The pressure filter was also contaminated with fine metal particles. The oil sump was drained and more metal was found.

1.1.7 The only external signs of engine distress were the discolouration of some exhaust risers and buckling and splitting of the exhaust collector pipes (see Figure 3).

1.1.8 The following day, in accordance with normal procedures, the Civil Aviation Authority (CAA) notified the Commission of the incident. By that time, the maintenance contractor had removed the propeller and the engine in anticipation of their being sent to an overhaul facility. The maintenance contractor advised that the previous evening a cleaner had inadvertently disposed of the drained engine oil, leaving insufficient for analysis.

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[2] The rules prescribe, among other things, the minimum flight visibility and distance from cloud, minimum heights and required aircraft equipment.

[3] Urgency was defined in the Aeronautical Information Publication New Zealand as "a condition concerning the safety of an aircraft… but which does not require immediate assistance". The pilot of an aircraft with an urgency condition should transmit the spoken signal "PAN PAN" 3 times followed by the nature of the condition, the crew's intentions and their position.

Figure 2
Debris from oil suction screen, with small test magnet at left

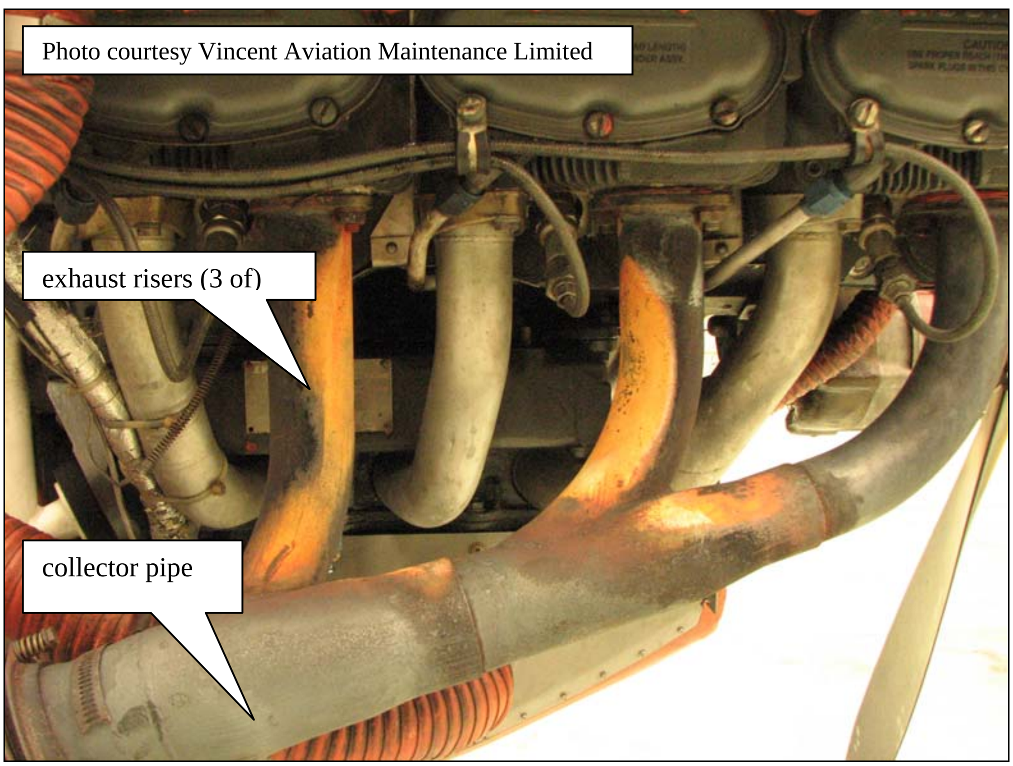

Figure 3
Right-hand exhaust pipes, ZK-KLC

1.2 Personnel information

1.2.1 The pilot had been employed part time by the operator since June 2005 and was taken on full-time after this incident. His flight experience, as of 27 November 2006, was as follows:

Licence, date issued	commercial pilot licence (aeroplane), 17 August 2004
GA8 type rating issued	25 November 2005
Medical certificate	class 1, valid until 2 August 2007
Most recent competency check	8 July 2006
Most recent biennial flight review	8 July 2006
Flying experience	840 hours total, including 255 hours on the GA8
Flying previous 90 days	159 hours, including 120 hours on the GA8
Duty/Flying previous 30 days	126.4 hours/51.2 hours
Duty/Flying previous 7 days	23.9 hours/9.2 hours
Time since end of last duty	12.5 hours
Time on this duty	1.2 hours

1.2.2 The pilot had worked for the operator on the 2 days prior to 27 November 2006, but not on the 4 days before that, when he had worked in his second job. He said that he was fit, rested and in good health prior to the incident flight.

1.2.3 On 1 December 2006, the pilot satisfactorily completed a check flight with the operator.

1.3 Aircraft information

1.3.1 The GA8 was an 8-seat utility aircraft with a high wing and a fixed tricycle undercarriage, manufactured in Australia by Gipps Aero. The aircraft was normally flown by one pilot and had maximum take-off and landing weights of 1814 kilograms.

1.3.2 According to the pilot's operating handbook, the GA8 could glide without engine power for approximately 1.65 nautical miles[4] (3 km) for each 1000 feet of altitude descended.

1.3.3 ZK-KLC was manufactured in November 2003 and imported into New Zealand by the operator that year. The CAA issued a New Zealand certificate of airworthiness in January 2004. By 27 November 2006, the aircraft and its engine had accrued 1959 hours since new. The most recent annual review of airworthiness had been completed on 12 January 2006.

Engine information

1.3.4 The GA8 was powered by a 6-cylinder, horizontally opposed, air-cooled, normally aspirated and fuel-injected Textron Lycoming (Lycoming) IO-540-K1A5 reciprocating engine, de-rated to 275 horsepower at full throttle and 2500 RPM. The de-rate was for noise certification. In an emergency, up to 2700 RPM were available by moving the propeller control lever past the normal control stop. The pilot said that he had used emergency RPM once in ZK-KLC, when taking off from a farm strip with a tail wind. The use of emergency RPM did not require an entry in the maintenance log or any special maintenance inspection.

1.3.5 The engine installation, including the design of cowling and baffles, was considered by Gipps Aero and Lycoming to be particularly efficient for cooling the engine.

[4] One nautical mile is approximately 1.86 kilometres.

1.3.6 The engine in ZK-KLC, serial number L-29048-48A, was manufactured in the United States in November 2003 and installed in the aircraft the same month.

1.3.7 The nominal time between engine overhauls was 2000 flight hours. Lycoming Service Instruction 1009AS, Recommended Time Between Overhaul Periods, stated that, because of variations in operation and maintenance, the recommended time between overhauls could not be guaranteed for any individual operator. However, if an engine were operated frequently, that is for more than 40 hours a month, as was ZK-KLC's, the time could be extended to 2200 hours.

1.3.8 On 6 November 2006, the CAA approved the operator's application to extend the time between overhauls for the engine and the propeller fitted to ZK-KLC to 2200 hours. The CAA noted that the extension for the engine was already available because the operator's "Approved Maintenance Programme makes reference to using the manufacturer's recommendations and [Service Instruction 1009AS] forms part of those recommendations".

1.3.9 Welded stainless steel exhaust manifolds were fitted to each side of the engine. The exhaust from the 3 cylinders on each side passed through "risers" into a collector pipe that went to a muffler (see Figure 3).

1.3.10 The pilot's operating handbook included a requirement to check the condition of the exhaust system as part of each pre-flight inspection. With the engine cowls in place, a pilot could see little more than the protruding exhaust stubs.

1.3.11 The Lycoming engine operator's manual required that the general condition of the exhaust manifolds be examined every 50 hours. The Gipps Aero service manual recommended that the exhaust system be "checked even more carefully as the number of hours increase". The operator had scheduled a check of the exhaust system at each 100-hour inspection.

1.3.12 To the operator's knowledge, the correct 100LL-grade fuel had always been used in ZK-KLC. There was no evidence, such as intake valve damage or burnt pistons, to suggest that aviation turbine fuel, of which very small amounts can cause detonation and serious damage in reciprocating engines, had ever been added to the tanks.

1.3.13 The pilot said that he normally used a cruise power of 2400 RPM and 24 inches and leaned the mixture to give a fuel flow of about 65 litres (L) per hour, "as per the flight manual", or to give an exhaust gas temperature that was 50^{o} Fahrenheit (F) less than the peak temperature.[5] The operator's copy of the Gipps Aero GA8 Instructor's Guide gave the 65% cruise power setting as 2400 RPM and 24 inches, with a fuel flow of 58-62 L per hour.

1.3.14 The pilot's operating handbook gave 2 options for cruise power: 75% (2500 RPM and 25 inches, with approximately 63 L per hour fuel flow) and 65% (2350 RPM and 23 inches, giving 52 L per hour). An alternative procedure given in the pilot's operating handbook was to lean to 100^{o}F on the rich side of peak exhaust gas temperature for best power, or 25-50^{o}F richer than peak for best economy. These settings were similar to those shown in the Lycoming Service Instruction 1094D, Fuel Mixture Leaning Procedures.

1.3.15 Figure 4 shows the crankshaft and other rotating parts of an engine of similar configuration to the Lycoming IO-540-K1A5. The crankshaft is not numbered in the figure, but items 4-7 are parts often referred to in this report.

1.3.16 A conventional camshaft was located above and parallel to the crankshaft. The camshaft lobes acted on self-adjusting tappets, also called hydraulic tappets (see Figure 5). These moved the push rods that operated the valve assemblies in each cylinder. The self-adjustment feature used engine oil pressure to keep the tappets in light contact with both the camshaft and push rods at all times in order to prevent impact loading and smooth the engine operation.

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[5] From the point where leaning gave the peak exhaust gas temperature, a lower temperature was achieved by enrichening the mixture.

1.3.17 The tappets were a flat-head type, made of tempered cast iron. The faces of the tappet heads were slightly convex so that each time the corresponding cam lobe met the face, a small amount of rotation was imparted to spread the wear across the face. This normal action left a circular pattern on the face. The overhaul manual required that any tappets that had a “wavy” appearance on the face, or any spalling, were to be rejected.

1.3.18 The tappets and camshaft had no stated life. A Lycoming engine overhaul facility advised that most operators replaced the tappets and camshaft with new parts at each engine overhaul because reconditioned parts were not covered by the manufacturer’s warranty.

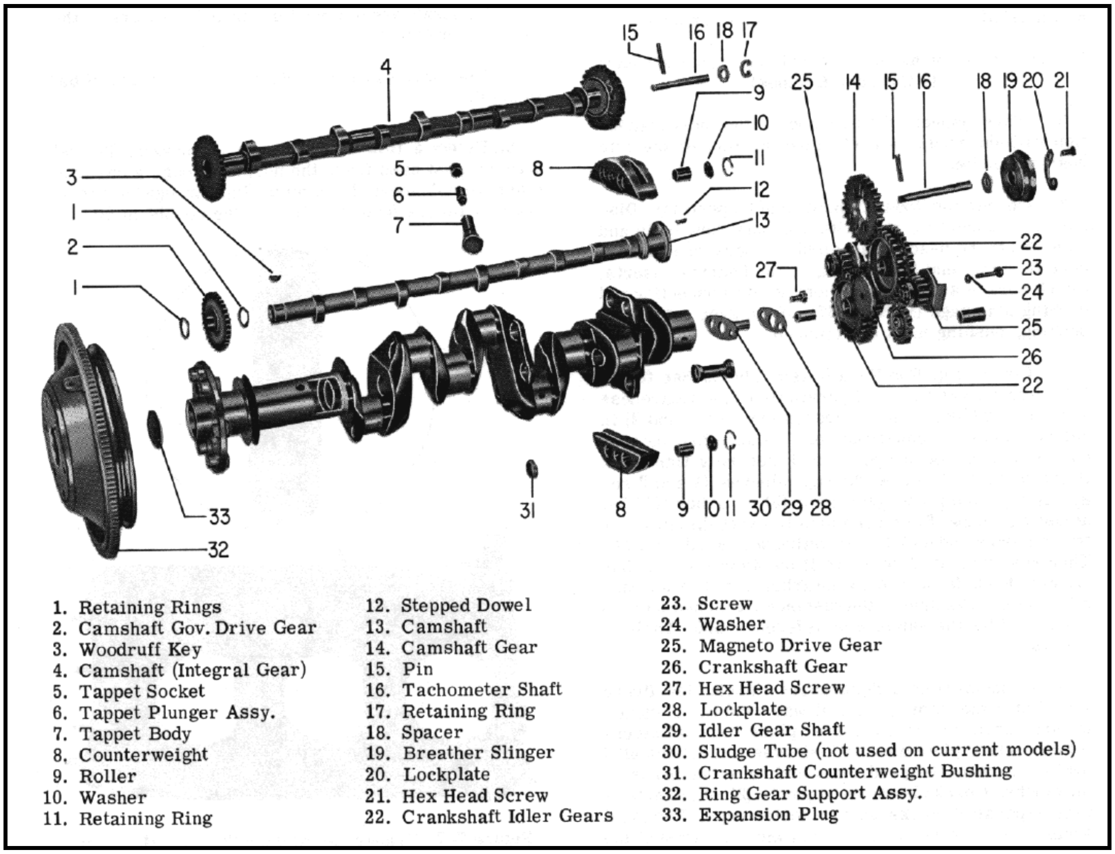

Figure 4
Diagram of a typical crankshaft and related parts
(Source: Lycoming overhaul manual)

1.3.19 Sticking valves are more often associated with high time engines. An indication of a sticking valve is an intermittent hesitation, or miss, of the engine. A valve usually sticks open, rather than closed, and usually stays stuck. That condition will be apparent to the pilot as a rough-running engine, often at the next engine start. Valve sticking is usually caused by contaminants or combustion residues in the oil adhering to the valve stem and guide. Preventative measures include ensuring clean air for the combustion process, clean oil, and proper engine warm-up before flight and cool-down prior to shutdown.

1.3.20 The wear characteristics of the exhaust valve guides fitted to the engine in ZK-KLC were better than those of earlier guides for which Lycoming specified a mandatory inspection at 400-hour intervals. However, Lycoming Service Instruction 1485A, Exhaust Valve and Guide Identification Procedure, dated 2 July 2003, recommended that even improved guides be inspected after 1000 hours of operation or halfway to the engine overhaul life, whichever occurred first, or if valve sticking were suspected. The operator had decided not to perform that inspection.

1.3.21 The pilot said that the aircraft had been difficult to start within the previous month, but that the problem had been rectified with a replacement magneto. He said there had been no rough running or unusually large magneto drops during engine run-ups. The pilot said he thought that he had probably flown ZK-KLC more often than the other pilot in the months prior to the incident and he had not noticed any abnormal engine performance or adverse trend.

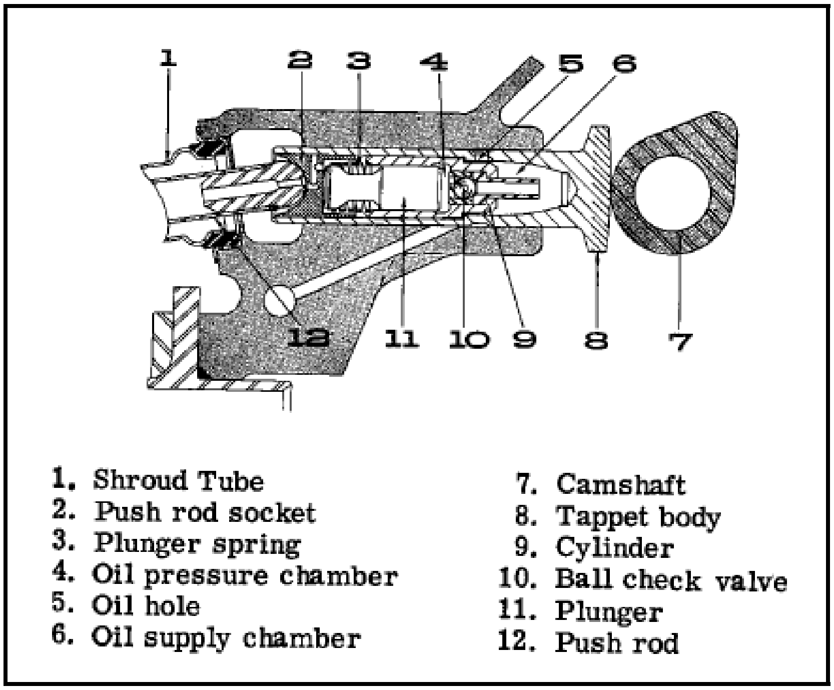

Figure 5
Diagram of a typical hydraulic tappet
(Source: Lycoming overhaul manual)

Oil system

1.3.22 Engine oil was drawn from a sump through a suction screen to an engine-driven oil pump mounted on the rear engine case. After passing through a full-flow pressure filter and a pressure-regulating valve, the oil was supplied to the various engine components.

1.3.23 The camshaft and tappet heads were lubricated by splash oil. The hydraulic tappets were supplied with oil under pressure, which then lubricated the push rods and the valve gear.

1.3.24 The minimum engine oil pressure was 25 psi and the normal operating range 55-95 psi. A red oil pressure warning light, set to illuminate when the pressure was 25 psi or less, was fitted to the instrument panel, but the pressure setting was not given in the pilot's operating handbook. The amplified emergency procedures in the pilot's operating handbook for low oil pressure said that a pilot must correlate the indicated oil pressure with the indicated oil temperature before deciding what action to take.

1.3.25 The sump capacity was 12 US quarts (11.4 L), but the pilot's operating handbook advised that replenishing to 10 or 11 quarts was adequate and would avoid the loss of oil through the crankcase breather. The Lycoming agent in New Zealand (the agent) suggested that 9 quarts were sufficient for routine operations, a view that Gipps Aero later adopted. The oil was topped up with new oil supplied from a bulk container held at the operator's premises at Picton aerodrome. In the case of complete replenishment after a scheduled check, the oil was provided by the maintenance contractor.

1.3.26 The operator used Phillips X/C aviation mineral oil, an ashless dispersant type with viscosity grade SAE 20W-50, which was approved by Lycoming and recommended by Gipps Aero.

1.3.27 The Lycoming engine operator's manual stated that the maximum permissible oil consumption was 0.75 quarts per hour at 2450 RPM and 0.60 quarts per hour at 2350 RPM. The maximum consumption at 2400 RPM was interpolated to be 0.68 quarts per hour. The pilot said that the GA8 engine used more oil than did the reciprocating engines of the operator's other aircraft. He said that after 2 return trips between Wellington and Kaikoura, about 3.6 flight hours, 2 quarts of oil were typically added. That equated to a usage rate of 0.56 quarts an hour.

1.3.28 The Flight Record forms for ZK-KLC included an oil uplift column that had often been used incorrectly, in that the flight date had been repeated in that column rather than the amount of oil added to the engine. In the week prior to 27 November 2006, during which 12.5 flight hours were logged, including 4 return flights between Wellington and Kaikoura, there was no record of oil being added. As a result, the actual recent oil consumption could not be determined.

1.3.29 The Lycoming engine operator's manual stated that the oil pressure and suction filters were to be removed, inspected, cleaned and reinstalled, and the oil sump drained and replenished with clean oil, after every 50 hours of operation. Lycoming mandatory Service Bulletin 480E, Oil and Filter Change and Screen Cleaning, dated 13 April 2005, repeated the requirement.

1.3.30 Lycoming Service Instruction 1425A, Suggested Maintenance Procedures to Reduce the Possibility of Valve Sticking, added, in part:

> Field experience has shown that engine oil contamination increases the possibility of sticking and/or stuck valves. This situation occurs when the contaminants in the engine lubrication oil become deposited on the valve stems, restricting the valve movement, and resulting in intermittent engine hesitation or miss. If corrective action is not taken to remove the deposits, a valve could become stuck causing engine damage.
>
> The prime cause of valve sticking is the accumulation of harmful contaminants in the oil and oil filter.

1.3.31 On 27 November 2006, the operator's maintenance schedule required airframe and engine checks, including oil and filter changes, to be done at 100-hour intervals. The maintenance controller said that the 100-hour interval had been interpreted, prior to his appointment, from the GA8 service manual, paragraphs 5-30-00 and 72-00-10. Chapter 5 of the manual contained the maintenance schedules, and specifically referred to 100-hour intervals, whereas chapter 72 (and 79) contained the maintenance procedures.

1.3.32 The GA8 service manual included the following requirements, in part:

> **5-30-00 Maintenance Schedules**
>
> The maintenance schedules required by Gippsland Aeronautics for the Daily Inspection and the scheduled maintenance of the GA8 at each 100 hour/annual airframe inspection, or as otherwise noted, form the remainder of this chapter.
>
> Unless otherwise approved by the applicable national airworthiness authority, all inspections listed in Maintenance Schedules are to be carried out in accordance with the procedures contained in this Service Manual.
>
> **72-00-10 Maintenance and Overhaul**
>
> Other than any specific procedures specified elsewhere in this Service Manual, detailed procedures for the maintenance and overhaul of the Lycoming IO-540 engine fitted to the GA8 aircraft can be found in the following documents:
>
> - Lycoming Operator's Manual covering IO-540 series engine, or…
>
> These documents are supplemented by Lycoming Service Letters and Service Bulletins as appropriate.
>
> **79-00-00 General**
>
> … Detailed procedures for the maintenance and overhaul of the integral engine oil system and its components may be found in the relevant Lycoming engine manuals.

1.3.33 Immediately after the oil change interval had been clarified, the operator amended its GA8 maintenance programme to comply with the 50-hour requirement. On 2 May 2007, Gipps Aero amended the GA8 service manual to clarify the 50-hour interval.

1.3.34 The operator did not have a spectrographic oil analysis programme for ZK-KLC before 27 November 2006, and it was not required to have one. However, following the incident an oil analysis programme was introduced.

Maintenance of ZK-KLC

1.3.35 The aircraft was maintained in accordance with the maintenance programme required by Civil Aviation Rules Part 119. From early 2006 and at the time of the incident, the contractor was based at Wellington airport, but on 1 July 2007 an associated company of the operator took over the contract.

1.3.36 The current maintenance contractor said that the previous contractor had queried the 100-hour oil change interval with the maintenance controller at the time. However, before the question could be resolved, both the maintenance controller and the maintenance contractor had changed, and the matter was not pursued.

1.3.37 The most recent unscheduled maintenance before the incident was the replacement of the left magneto on 10 November 2006 (see paragraph 1.3.21).

1.3.38 The most recent scheduled maintenance before the incident was a 100-hour inspection carried out on 25 October 2006 at 1903 hours total time. On 28 April 2006, both the left and right exhaust muffler assemblies were replaced because they were cracked. A crack in the left exhaust muffler had been repaired on 14 February 2006.

1.4 Tests and research

Engine tear-down

1.4.1 The engine was taken to an approved overhaul facility for examination under the Commission's supervision. Apart from an initial, limited inspection to gauge the extent of the damage, the tear-down was carried out in the presence of the agent, who had extensive knowledge of the IO-540 engine installation in the GA8.

1.4.2 The exterior of the cylinders showed signs of salt corrosion. As far as could be determined, the magneto timing was correctly set. The condition of all spark plugs was normal.

1.4.3 A "fuzz" of ferrous and non-ferrous material was seen in the valve gear. When the push rods were removed, the sockets of some adhered by oil to the rods and came out with them.

1.4.4 Internal damage included tappet disintegration, chipped cylinder barrel skirts, abraded piston skirts and gouging of the connecting rod caps. The crankshaft and its counterweights were intact. An oil control ring on one piston was broken, but the lack of cylinder scoring suggested that the ring broke during disassembly. The main bearings had very light scoring.

1.4.5 A grub screw from the idler gear support shaft in the propeller governor assembly, implicated in a previous incident overseas (see paragraph 1.6.5), was correctly positioned.

1.4.6 The bulk of the debris in the engine was broken tappets (see Figure 6). Only the 2 tappets in the #6 cylinder had not been broken; their faces retained the slightly convex profile. There was evidence on the crankcase counter bore surfaces at all tappet positions that debris had been trapped between the underside of the tappet heads and the crankcase.

1.4.7 The tappet for the #4 cylinder exhaust valve was the most damaged, with the head worn away and the body chipped in 2 places at the push rod end. The chips were retained in the tappet within the crankcase, as was the push rod socket (see Figure 7). Because of the head damage, the #4 exhaust valve tappet was 9.75 millimetres (mm) shorter overall than a serviceable IO-540 tappet.

1.4.8 There was a witness mark on the end of the #4 exhaust valve push rod shroud tube that matched the push rod socket edge (see Figure 7). Wear marks on the socket showed that during normal operation nearly half of the socket's 17.56 mm length extended out of the tappet body.

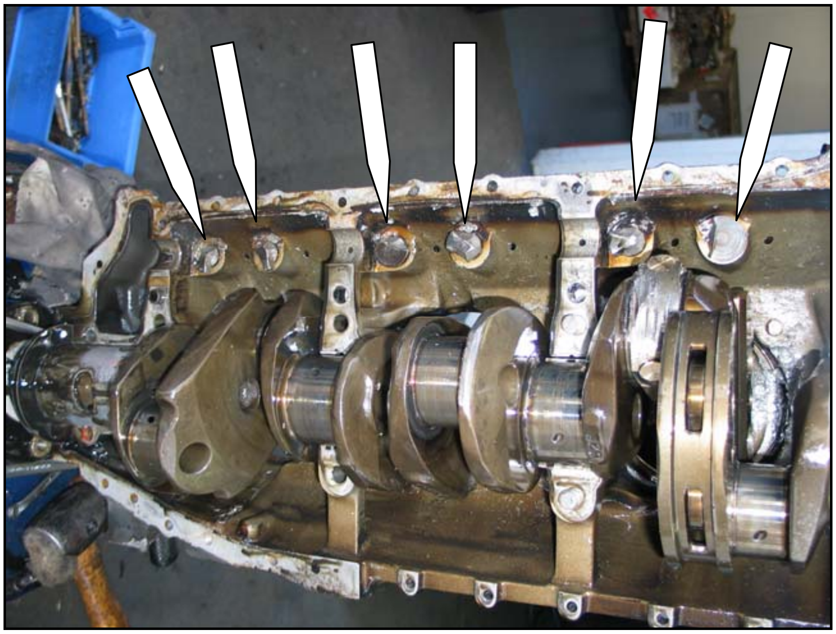

Figure 6
One crankcase half, showing broken tappets

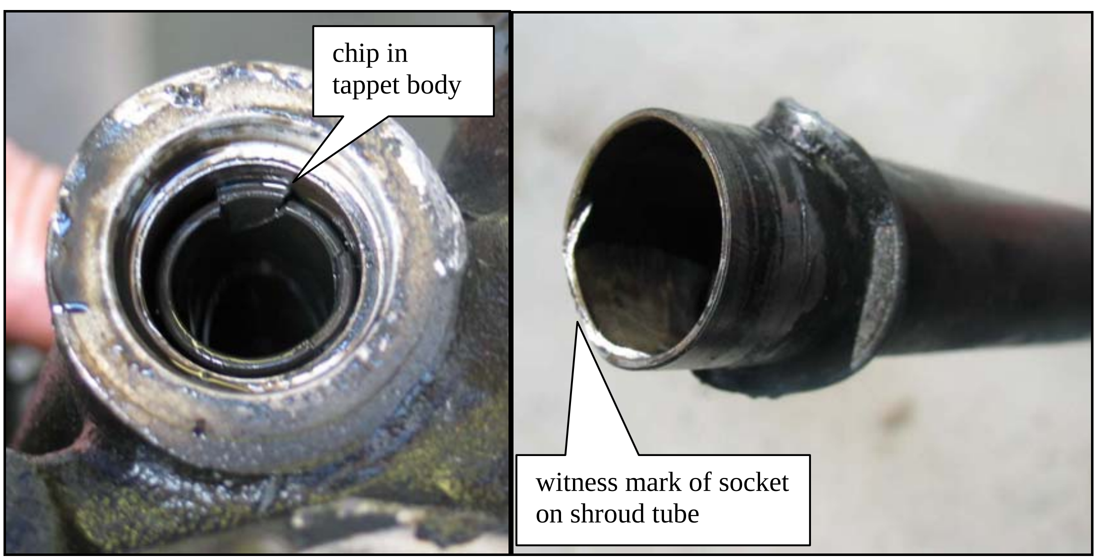

Figure 7
#4 exhaust valve tappet body (left), and push rod shroud tube (right)

1.4.9 The clearances of all valve stems and guides were measured under the supervision of the Commission and they were found to meet the Lycoming overhaul manual limits with the due allowance for time in service. None of the push rods was bent and none of the valves was damaged. There was no visible sign of coking of the valve guides. None of the piston crowns showed evidence of having been struck by a valve.

1.4.10 The accessory drives were undamaged, although there was shallow scoring on the inside of the engine-driven oil pump. The fuel control unit was bench tested and the output flow rates found to be set just above the minimum (leanest) values. The fuel nozzles were clear.

1.4.11 Engineers considered that the condition of the engine was typical for its time in service. No evidence was found of poor or inadequate lubrication, or that the engine had been operated with an excessively lean mixture or excessive temperature.

1.4.12 Experienced aircraft maintenance engineers had the opinion that the tappet disintegration was a rare event and unlikely to have been related to the extended time between oil changes. They said that the damage could have taken anywhere from a few minutes to 20 minutes to occur, but they were surprised that there was no warning of the impending failure.

Laboratory examination of tappets and camshaft

1.4.13 An independent material-testing laboratory was engaged to examine the tappet and camshaft materials, and to comment on the wear and damage.

1.4.14 The laboratory examination found no evidence of spalling on the camshaft lobes or tappet heads, and noted that all of the tappet fractures were brittle fractures. The undamaged tappet heads had circumferential and radial wear marks consistent with normal operation.

1.4.15 The microstructure of the tappets was examined under microscope, and the chemical composition of the tappets and the camshaft was determined using X-ray fluorescence. The carbon content of the tappets was determined using the Leco combustion method.

1.4.16 In discussing the relative hardness of the camshaft and tappets, the laboratory commented:

> Since nitriding[6] [of the camshaft lobes] provides a very hard surface… the hardness of the tappets should be correspondingly higher to nearly match that of the camshaft lobe to reduce preferential wear of the tappet. However, hardness levels for tappets operating with nitrided camshaft lobes should be between 400 HV[7] and 600 HV… equivalent to 41-55 HRC. While the hardness of the tappet head was correspondingly higher [being 710 HV, or 60 HRC], it was very high compared with that recommended. Such a high hardness may have made the tappets more brittle than ideal.

1.4.17 The scientist further commented that the hardness (and brittleness) was a permanent property of the material, so if being more brittle than recommended was a detrimental factor, the tappets would have failed much earlier.

1.4.18 The laboratory's conclusions were as follows:

- the materials of manufacture were fit for purpose
- the nitrided condition of the camshaft lobe was satisfactory
- the heat-treated condition of the tappet rendered the tappet head harder than recommended according to literature and probably more brittle
- the source of the tappets is suspected as they did not resemble the types illustrated and described in the [provided engine overhaul] manual
- the wear on the camshaft lobes was variable with evidence of scuffing but no distress. The damage to the lobes resembled impact or chipping from hard debris, possibly from disintegrating tappets
- wear on the tappet heads was typical and light with very slight ridges
- no evidence of fatigue was seen on the fractures.

1.4.19 Reference to Lycoming manuals confirmed that the tappets were approved parts.

[6] Nitriding was a production treatment used to harden the surfaces of certain steel alloys.
[7] HV and HRC refer to alternative methods of measuring hardness.

Condition of exhaust pipes

1.4.20 The maintenance contractor considered that the deformation of the exhaust risers was not uncommon for pipes that had reached the end of their service life, and was adamant that there had been no unacceptable damage or buckling at the previous 2 inspections. Gipps Aero had no previous knowledge of exhaust risers splitting, and besides noting that a split could lead to carbon monoxide contamination of the cabin or fire, said that the cause was thought to be over-leaning of the mixture. No evidence of excessive operating temperatures, such as relatively clean piston crowns, was seen.

1.4.21 Gipps Aero, the Lycoming agent and the maintenance contractor all suggested that the discolouration of the exhaust pipes was connected to operating in a salt air environment. Other engine specialists considered that the colour and distortion were strongly indicative of excessively lean engine operation.

1.4.22 A specialist exhaust pipe repairer said that the pipes were almost in a dangerous condition and the need for rectification could have been apparent for 200 or more flight hours. He said that the exhaust systems of most general aviation aircraft required high maintenance, and few aircraft had exhaust pipes that lasted as long as the nominal time until engine overhaul. In his opinion, the similar damage on each riser indicated the engine had been operated too lean, too often.

Oil condition

1.4.23 An independent oil-testing company and a major oil supplier advised that the amount of oil recovered from the engine sump was insufficient for proper analysis. They said some chemical and physical parameters of the small sample could have been determined, but would not have been reliable indicators of the oil age or the long-term engine operating conditions. A full analysis would have required comparison with a clean sample from the same batch of oil.

1.4.24 The independent material-testing laboratory said that repeated contact between camshaft lobes and tappets, if lubricated with dirty or old oil, could lead to spalling of the surfaces. Roughened surfaces disrupted the oil film and led to increased sliding friction and further spalling.

1.5 Organisational and management information

1.5.1 Soundsair was an established Part 125[8] air operator providing scheduled services and tourist flights between Wellington and northern parts of the South Island. The chief pilot, as at 27 November 2006, had been with the company for 2 years and had held the appointment for 6 months. A former chief pilot was the Senior Person responsible for check and training[9]. A licensed aircraft maintenance engineer was appointed Maintenance Controller in February 2006.

1.5.2 On 27 November 2006, the company operated 6 aircraft types and employed 8 pilots, any of whom could be rostered to fly the GA8.

1.5.3 Civil Aviation Rule 91.605(b)(1) stated in part:

> (b) The operator of an aircraft that is—
> (1) used for air operations under the authority of an air operator certificate issued in accordance with Part 119 must maintain the aircraft in accordance with the maintenance programme that is required under Part 119 for the issue of the air operator certificate;…

1.5.4 The Rules and Advisory Circular were inconsistent as to whether the CAA accepted or approved maintenance programmes for Part 119 operators. There was a corresponding doubt

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[8] Civil Aviation Rule Part 125, Air Operations – Medium Aeroplanes, prescribed the operating requirements for, in broad terms, air operations using aeroplanes that have a seating configuration of 10 to 30 seats, or using a single-engine aircraft operated under instrument flight rules. The company operated 2 aircraft of the second category.
[9] The check and training captain returned to the operator in early 2008 and was again appointed chief pilot.

among some operators and CAA staff. However, most references indicated that programmes were accepted. For example, Advisory Circular 91-12/119-5 stated at page 8:

> Air transport operators are required to have a maintenance programme included in their documented system. This programme is accepted as part of the issue of their air operator certificate.

and at page 21:

> Manufacturer's maintenance programmes are acceptable to the director without further approval.

1.6 Additional information

Other operators' experience

1.6.1 In New Zealand, there were 6 GA8 aircraft registered to 4 operators. The other operators reported no problems with their IO-540-K1A5 engines, all of which had less time in service than ZK-KLC's. Although all of the other operators had complied with the 50-hour oil change interval, one said it was initially confused by the Gipps Aero maintenance manual requirements in that regard.

1.6.2 One maintenance organisation said that it had replaced a set of exhaust pipes on a GA8 earlier than engine time between overhauls because of muffler failure.

1.6.3 The largest operator of the GA8 was based in Australia. Its maintenance quality manager said that its IO-540 engines, although operated in hot and dusty conditions, had all achieved the 2000-hour time between overhauls, and the exhaust pipes had also reached or exceeded that life.

1.6.4 Gipps Aero estimated that it had installed 190 Lycoming IO-540-K1A5 engines, and it knew of only 2 tappet failure events. One was with a Caribbean operator, which found debris from a tappet in the oil suction screen after 150 hours of operation. Gipps Aero said that there was corrosion pitting on the tappet face, and the face hardness was at the lower limit.

1.6.5 The other event occurred in China. A light aircraft landed with a rough-running engine that was not shut down until after a prolonged period of taxiing. The agent said that a grub screw from the idler gear support shaft in the propeller governor assembly had fallen out and lodged under a tappet head. The tappet head failed and the debris got under other tappet heads, leading to a progressive break-up of all the tappets.

1.6.6 In November 2006, a New Zealand helicopter fitted with a Lycoming IO-540AE-1A5 experienced a catastrophic engine failure after 845 hours' total time in service. The failure occurred approximately 540 flight hours after major engine components, including the pistons, valves and tappets, had been replaced because of an inadvertent use of aviation turbine fuel. Lycoming concluded that "the most likely initial failure point [was] the fracture of a tappet".

1.6.7 Although the helicopter engine was a similar model to that in ZK-KLC, the installation and operating conditions of helicopter engines were different from those of fixed-wing aircraft. In addition, that helicopter earlier had won an air race in circumstances that suggested the engine had been operated at power levels in excess of those recommended.

1.6.8 However, the agent understood that the tappets in the helicopter engine were from the same vendor and manufacturing batch as those used in ZK-KLC. He acknowledged that "a number" of tappet bodies were rejected in each batch, but Lycoming had tested engines fitted with rejected tappets and still achieved the nominal time between overhauls.

1.6.9 Lycoming suggested 3 possible reasons for tappet break-up:

- a foreign object caught under the head
- valve bounce, although that did not occur until approximately 4000 RPM
- a stuck valve.

1.6.10 Lycoming had, since 2005, manufactured engines and fitted factory-overhauled engines with a more robust roller tappet design that resulted in less friction and wear, and was said to have strongly advocated the replacement of flat-head tappets with roller tappets in the IO-540 engine.

Survival considerations for over-water flights

1.6.11 Civil Aviation Rule 91.525, Flights over water, applicable to all flights, stated in part:

> (a) An aircraft operated on over water flights must be equipped with —
>
> (1) for single-engine aircraft, or multi-engine aircraft unable to maintain a height of at least 1000 feet AMSL[10] with one engine inoperative, on flights more than gliding distance from shore, one life preserver for each person on board stowed in a position readily accessible from each seat or berth; and…
>
> (3) for single engine aircraft, or multi-engine aircraft unable to maintain a height of at least 1000 feet AMSL with one engine inoperative, on flights of more than 100 [nautical miles] from shore —
>
> (i) sufficient life rafts with buoyancy and rated capacity to accommodate each occupant of the aircraft; …

1.6.12 For air transport operations, Civil Aviation Rule 135.87, Flights over water, stated in part:

> (a) A person performing an air operation must not operate over water more than 10 [nautical miles] beyond gliding or autorotational distance from shore unless —
>
> (1) life rafts are carried of sufficient rated capacity to carry every occupant of the aircraft; and
>
> (2) a life preserver is worn by each passenger.

1.6.13 ZK-KLC was not equipped with a life raft for this flight. The operator's chief pilot said that he had not realised that a flight operated directly between Wellington and Cape Campbell had to be at or above 3000 feet when mid-Strait, if a life raft was not carried, in order to comply with the above Rule. Weather or air traffic control requirements could dictate a shorter over-water route, but the operator had not specified the compliance considerations for the direct route. Following the incident, the operator promulgated a minimum altitude requirement for the direct route between the Islands.

1.6.14 The operator had not previously published information for its pilots on ditching techniques, but the check and training captain covered the topic during aircraft type rating and crew competency check flights. After this incident, the chief pilot reviewed the operator's preparedness for an aircraft ditching and the training given to its pilots in ditching techniques and water survival.

2 Analysis

The flight

2.1 The pilot was qualified to perform the intended flight, and weather was not a factor. As soon as he was aware of an engine defect, he took the recommended action by reducing power and returning to the airport. The south coast of the North Island offered few places to attempt a forced landing, if one had become necessary, so it would have been prudent for him to have used the urgency signal when he advised air traffic control of the problem.

2.2 The reluctance of some pilots to declare urgency had been noted previously by the Commission and in accident reports by other agencies. This example supported the safety recommendation

[10] Above mean sea level.

made in report 06-009 to the Director of Civil Aviation that he provide education to pilots and others regarding emergency communications and requests for assistance[11].

2.3 Although the pilot intended to cruise at 3000 feet to Cape Campbell, the operations manual at that time did not contain a minimum altitude for that route. A lower cruise altitude would have required a life raft to be on board. The minimal company documentation concerning relevant operational, training and survival considerations indicated that the operator, and the CAA through its audit and inspection programme, had not fully considered the risk of ditching with over-water air transport operations by single-engine aircraft.

2.4 Although these matters were subsequently corrected by this operator, a safety recommendation was made to the Director of Civil Aviation that he inspect all air transport operators of single-engine aircraft to establish their means of ensuring compliance with Civil Aviation Rule 135.87, Flights over water.

The engine failure

2.5 The pilot reported that immediately after the engine "gave a kick" he saw that the oil pressure had reduced and was fluctuating, which was an indication that the oil screen was already clogged or that the engine had a big oil leak. The oil pressure did not fall enough to illuminate the warning light. The debris in the sump was almost entirely broken tappet heads and shavings off the connecting rod caps, so the tappet failures must have been occurring before the engine faltered. As the pilot had not noticed anything unusual before the "kick", it was probable that the damage began on the incident flight. The presence of light scoring only on the main bearings supported the view that the tappet break-up sequence had occurred over a short timeframe.

2.6 The engine failed 41 flight hours before the nominal time for overhaul. One hypothesis examined was that the failure originated with a stuck #4 exhaust valve, and that the engine was susceptible to valve sticking because the operator had not changed the oil every 50 hours and had not inspected the exhaust valve guides as recommended by the Lycoming Service Instruction 1485A.

2.7 The internal damage suggested that the first component to fail was a part of the #4 exhaust valve train, between the camshaft and the valve. Possible causes included the following:

- a design, material or manufacturing deficiency affecting a component
- an installation or maintenance deficiency, including incorrect lubrication
- the operating environment or pilot handling.

2.8 Metallurgical examination found no pre-existing defect with the camshaft or camshaft lobes.

2.9 The tappets were original parts and those tested met the dimensional specifications. Although the hardness of the tappet heads was at the top end of the typical range for the material, the laboratory opinion was that the achieved life indicated that the hardness had not been detrimental to the tappets.

2.10 It was probable that the #4 exhaust valve tappet was the first to break, because it was the most eroded and its push rod socket had been displaced between the shroud tube and the tappet body. There was no evidence that the #4 exhaust valve tappet had failed because of a design, material or manufacturing deficiency. The subsequent tappet failures were due to the increasing amount of debris that became trapped between the tappet heads and the crank case.

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[11] Report 06-009, Boeing 767-319, ZK-NCK, fuel leak and engine fire, Auckland International Airport, 30 December 2006.

2.11 A foreign object, such as a discarded screw that found its way into the engine during oil replenishment, could have caused the first tappet failure, but no such object was found.

2.12 Although Lycoming had changed to a different type of tappet for engines manufactured and overhauled since 2005, the incidence of flat-head tappet failures was very low. Lycoming had concluded that the helicopter engine failure in 2006 began with a tappet failure, but that was an unexpected finding because the tappets in that engine had been replaced only 540 flight hours earlier. The helicopter engine had had a short, hard life, and was a different variant of the IO-540 engine from that in ZK-KLC, so the 2 incidents could have been completely unrelated.

2.13 In order for the #4 exhaust valve push rod socket to have displaced from the tappet body enough for it to strike the shroud tube, a gap had to have opened between the push rod and the hydraulic tappet (see Figure 5). The single witness mark on the shroud tube showed that the socket had been displaced or misaligned only once.

2.14 The hydraulic feature of the tappets automatically kept them in contact with their respective cam shaft lobes and push rods at all times, via the plungers and sockets. As the #4 exhaust valve tappet head was progressively broken away, the internal oil pressure that kept the tappet in contact with the cam also acted in the other direction to push the socket further out of the tappet body. About half of the socket extended from the tappet body during normal operation, and the difference in length between the damaged #4 exhaust valve tappet and a serviceable tappet was also about half a socket length. Therefore, once the tappet head had been worn away to that extent, there was enough space for the socket to be displaced. The socket probably did not displace completely, but did extend enough for the push rod to apply an un-resisted side force that caused the tappet body edge to chip.

2.15 The engine falter could have been when the socket was misplaced after most of the tappet head had gone or could have occurred in any one of the cylinders that had damaged tappets. The method of operation of the hydraulic tappets meant that the engine operation appeared normal to the pilot until the break-up was well advanced.

2.16 Lycoming maintained the view that the socket had misplaced because the #4 exhaust valve had stuck and that a contributory factor was the non-accomplishment of (the non-mandatory) Service Instruction 1485A. There was no evidence, such as a bent push rod, that the valve had stuck closed. There was no evidence of coking within the valve guides, nor of any prior valve sticking. Measurement confirmed that all of the exhaust valve guides and stems were within the manufacturer’s service limits. Therefore, although valve sticking could have occurred later in the break-up sequence, it was unlikely that a stuck #4 exhaust valve had initiated the engine failure.

2.17 The pilot’s reported use of emergency RPM on one occasion would have had no detrimental effect on the engine, which was certified at that power level. The maximum 2700 RPM was well below the level that Lycoming said would cause valve bounce.

2.18 The order of symptoms reported by the pilot, the socket witness mark on the shroud tube, the absence of damage to the push rod and valves, and the valve train geometry together suggested that the #4 exhaust valve tappet head broke first, but why that happened was not determined. No design, material or manufacturing deficiency was found.

Extended oil change intervals

2.19 The initial error in the oil change interval might have been due to a misinterpretation of the service manual, which has since been clarified by Gipps Aero. Because the CAA accepted a maintenance programme that was based on a manufacturer's schedule, it was unlikely that the error would have been found during the acceptance process. Indeed, even if the programme had been scrutinised, CAA staff could have made the same misinterpretation. However, the error would have been minimised if the maintenance contractor at the time or the current contractor had resolved with the operator why a 100-hour interval was specified.

2.20 The engine in ZK-KLC was said to have a high oil consumption rate, but the reported rate was within limits and a higher consumption rate was not unusual for an engine close to its nominal time for overhaul. Replenishing the engine oil to more than 9 quarts would normally lead to excessive oil venting, which would also contribute to a high consumption rate. Although the most recent Flight Records did not show any oil uplifts, the presence of signatures on successive dates indicated that the oil had probably been checked. The Commission considered it very unlikely that ZK-KLC would have been operated for more than 12 hours without any oil being added.

2.21 Oil best achieved its purposes when new, and its lubricating properties were known to decline over time. Contaminants in the oil, which came from inducted air, combustion products and engine wear, were removed only with a complete oil change.

2.22 Because there was no evidence of damage or deterioration in the engine that could be attributed to poor lubrication, the Commission concluded that the extended oil change interval, although contrary to the manufacturer's instructions, was not a factor in this engine failure.

Condition of exhaust pipes

2.23 The poor condition of the exhaust pipes was probably not a consequence of the rapid tappet break-up. The pilot did not recall the engine and oil temperatures, but even if they were higher than normal, they were unlikely to have been high enough in the remaining short flight time at reduced power to have caused the distortion seen, especially as the cowls and baffles were considered to be effective at cooling the engine.

2.24 The aircraft was used predominantly for air transport flights at relatively low altitudes, and although different sources gave different fuel flows for leaning the engine mixture when setting cruise power, the operator's practice gave a richer mixture than the manufacturer recommended. The engine tear-down did not find evidence that the engine had been operated with excessively lean mixtures.

2.25 The damaged areas of the pipes could not be seen by pilots during pre-flight inspections. The mufflers had been replaced 7 months earlier, so it would have been normal for the exhaust system condition to be inspected at that time.

2.26 The conflicting expert views as to the likely condition of the exhaust pipes at the most recent 100-hour inspection in October 2006 were not resolved, and the cause of the buckling and splitting was not conclusively determined.

3 Findings

Findings are listed in order of development and not in order of priority.

3.1 The pilot of ZK-KLC on 27 November 2006 was qualified and fit to operate the flight.

3.2 Given the inhospitable location, it would have been prudent for the pilot to have declared urgency to air traffic control as soon as he detected the engine problem.

3.3 The ditching risk that was present with over-water air transport operations with single-engine aircraft, and the means of mitigating that risk, had not been fully considered by the operator or the CAA.

3.4 The engine failure originated with the break-up of a tappet head, but the cause of the tappet failure was not determined.

3.5 No evidence was found to suggest that the type of operation or engine handling by any pilot was a factor in the engine failure.

3.6 Although the aircraft had been maintained in accordance with the operator's maintenance programme, the programme did not comply with all of the engine manufacturer's requirements.

3.7 Because there was no damage or deterioration in the engine that could be attributed to poor lubrication, it was concluded that the extended oil change interval was not a factor in the engine failure.

4 Safety actions

4.1 On 30 November 2006, the chief pilot initiated a review of the operator's preparedness for an aircraft ditching and the training given to its pilots in ditching techniques and water survival.

4.2 On 3 December 2006, the operator issued an Operation Notice reminding pilots to use the Flight Record oil uplift column correctly.

4.3 On 8 January 2007, the operator issued an Operation Notice and amended the GA8 Route Guide to specify that the minimum altitude to cross Cook Strait on the direct Wellington to Cape Campbell route was 3000 feet outside 10 nautical miles from either Wellington or Cape Campbell. The Route Guide added that, "Controlled visual flight rules flight at the highest practical altitude should be a priority at all times".

4.4 On 30 March 2007, the operator amended its GA8 maintenance manual to require oil and filter changes every 50 hours, and instituted a spectrographic oil analysis programme.

4.5 On 2 May 2007, Gipps Aero added a 50-hour inspection requirement for the oil system to section 5-30-00, Maintenance Schedules, of the GA8 service manual.

4.6 On 2 July 2008, Gipps Aero advised that:

> We currently recommend for normal operations to allow the oil [quantity] down to approximately 8 quarts, then top up to 9 quarts.… We will examine our flight manual wording on this point and expand… if deemed necessary.
>
> [We] have noted your comment re the 25 PSI set [oil] pressure [warning light] is not specified in the flight manual. We will examine this situation and list set pressure if considered necessary.

5 Safety recommendation

5.1 On 27 May 2008, the Commission recommended to the Director of Civil Aviation that he:

Inspect all air transport operators of single-engine aircraft to establish their means of ensuring compliance with Civil Aviation Rule 135.87, “Flights over water” (023/08).

5.2 On 3 July 2008, the Director of Civil Aviation replied, in part:

> The CAA accepts the… safety recommendation, and will look to include the required work into its work programme in the general aviation area. (023/08)

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Hon W P Jeffries
Chief Commissioner

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