Piper PA-28-161 Cherokee Warrior II, G-MAND

AAIB Bulletin No: 7/2003	**Ref: EW/C2001/06/34**	**Category: 1.3**
Aircraft Type and Registration:	Piper PA-28-161 Cherokee Warrior II, G-MAND	
No & Type of Engines:	1 Lycoming O-320-D3G piston engine	
Year of Manufacture:	1981	
Date & Time (UTC):	30 June 2001 at 1251 hrs	
Location:	Wolverhampton Airport, Halfpenny Green, West Midlands	
Type of Flight:	Private (Training)	
Persons on Board:	Crew - 2	Passengers - None
Injuries:	Crew - 2 (Minor)	Passengers - N/A
Nature of Damage:	All landing gear legs and left wing detached	
Commander's Licence:	Commercial Pilot's Licence with Assistant Flying Instructor Rating	
Commander's Age:	24 years	
Commander's Flying Experience:	327 hours (of which 287 were on type)	
	Last 90 days - 97 hours	
	Last 28 days - 62 hours	
Information Source:	Aircraft Accident Report Form submitted by the pilot, and component examination by AAIB	

Synopsis

The aircraft, with two pilots on board, suffered an engine failure shortly after takeoff from Runway 28 at Halfpenny Green Airfield. The instructor pilot managed to effect a landing on the reciprocal runway but overran the paved surface. All three landing gear legs failed during the overrun and the left wing detached. The pilots suffered minor whiplash injuries. At the time of the accident the engine had accumulated 1,865 hours since its rebuild in 1997. Examination of the engine revealed severe wear to the engine valve operating mechanism and extensive cracking of the No 1 cylinder assembly. Wear to the valve operating mechanism was considered not to be a factor in this accident but the use of an oil additive, mandated by the manufacturer for other engine models, would possibly have reduced this wear. The total power loss had probably resulted when a substantial pre-existing cylinder head crack had suffered a rapid and large extension around most of the cylinder head circumference allowing the crack to open up and vent the cylinder. A safety recommendation has been made concerning the reduction in wear to the valve operating mechanisms, in this and other similar engine types, by mandating the use of oil additives.

History of the flight

The aircraft was on its third flight of the day, planned as an instructional trip towards revalidation of the second pilot's Private Pilot's Licence. The Technical Log indicated that the fuel contents were around 100 litres; fuel water drain checks had been carried out before the first flight of the day. Information from the instructor indicated that the second pilot's pre-flight inspection of the aircraft and engine power checks revealed no signs of anomalies. The second pilot executed a normal takeoff on Runway 28 at Wolverhampton Airfield, with the wind from 280° at 10 kt, gusting to 20 kt. Runway 10/28 is 1090 metres long and 23 metres wide with an asphalt surface.

Shortly after takeoff both pilots checked the engine instrument indications and found them to be normal. At approximately 700 feet agl the engine began to run roughly and the instructor took control. Almost immediately, the engine speed reduced to around 1800 rpm, from its full power setting. The instructor levelled off and decided to fly a low level circuit and land back but the engine then appeared to loose all power output. He was unable to locate a suitable forced landing area ahead and so, at around 600 feet agl, turned back towards the airfield to make a forced landing on Runway 10, informing the Tower of the situation and his intentions.

On the approach the instructor sideslipped the aircraft to loose height but, with the strong tailwind, was unable to touchdown until about half way along the runway. He was unable to stop in the runway length remaining and the aircraft ran off the end, went through the airfield boundary hedge, passed across a lane and came to rest in an adjacent field. All three landing gear legs failed during the overrun and the left wing detached and came to rest inverted on top of the right wing. There was no fire.

The pilots were each wearing a harness with a lap strap and an inertia reel diagonal upper torso restraint strap and were uninjured, with the exception of minor whiplash effects, and both were able to evacuate through the right hand main door.

Engine Examination

A strip examination of the engine and testing of the magnetos, carburettor and engine-driven fuel pump were carried out by the AAIB at an engine overhaul facility. The results of the accessory tests were normal, but two anomalies with the engine were found:

Valve Operating Mechanism

The engine valves are driven open against their springs by integral cam lobes formed on a case-hardened steel camshaft. The lobes act on a chilled cast iron follower body for each valve, which in turn drives a hydraulic plunger, push rod and rocker arm mechanism. The exhaust valves are operated by individual camshaft lobes, but the inlet valve lobes each operate two valves.

Severe distress to the operating mechanism for Nos 3 and 4 inlet valves was evident. The camshaft lobe was found severely worn, with its height reduced to 0.309 inch, compared to 0.352 inch for the other lobes, and both follower bodies had extensive surface pitting of the face contacted by the cam. Metallurgical examination found that both inlet valve camshaft lobes had a consistent and tempered microstructure, with a uniform 1 mm thick hardened layer present, except in the worn region of the Nos 3/4 inlet valve lobe. The examination indicated that this lobe had suffered overheating and consequent softening and that, as a result, the followers had suffered from rolling contact fatigue damage. The results suggested that the most likely cause of the degradation was insufficient lubrication.

No 1 Cylinder

Extensive cracking of the No 1 cylinder assembly (Engine Components Part No 65099-REV-1) was evident. This comprised two generally circumferential cracks in the aluminium wall of the cylinder head that had linked the upper and lower spark plug holes via both the forward and aft sides of the head. The cracks extended through the whole wall thickness, and thus almost completely separated the head from the cylinder. The ends of the crack had grown along slightly different planes and the head remained marginally attached to the cylinder by a 0.8 x 0.4 inch sized unfailed portion of the wall.

Damage to the exhaust system, consistent with the effects of ground contact of the nacelle region of the aircraft, indicated that abnormal loads had been applied to the No 1 cylinder assembly via its exhaust pipe during the overrun. However, heavy sooting of the portion of the fracture between the lower spark plug hole and the inlet valve port, across the whole thickness of the cylinder head wall section, showed that this part of the crack had been present while the engine had been operating. This crack, comprising approximately 30% of the total crack length, was 3 inch long and the wall thickness was generally around 0.5 inch. Much of the remainder of the fracture surfaces appeared to be slightly discoloured, with light soot deposits. In addition to the circumferential cracking, a second crack was also evident, between the lower spark plug hole and the exhaust valve port. This crack also extended through the whole section. Parts of this crack were also sooted, indicating that it too had been present while the engine had been operating.

Metallurgical examination found no evidence of progression of either crack by a fatigue mechanism, except in two small regions of the circumferential crack adjacent to the unfailed area. The other portions of the cracks had a rough and dimpled morphology similar to that produced by tensile overload failure. Microsection examination and hardness tests did not suggest an abnormality with the cylinder head material.

Aircraft History

At the time of the accident the aircraft had accumulated 6,237 operating hours since manufacture. A manufacturer's factory newly rebuilt engine had been installed in 1997, since when the aircraft had been operated for flying training with the same operator and maintainer. In late 1999, at the time of a top-end overhaul, four new cylinder assemblies were fitted, 693 hours before the accident. At the time of the accident the engine had accumulated 1,865 hours since the 1997 rebuild.

Aircraft documentation indicated that the aircraft had generally been operated frequently and had been serviced and checked in accordance with the Maintenance Schedule (CAA/LAMS/A/1999 Issue 1). Following a run-in period the engine had been operated on Aeroshell W80 or W100 oil. The schedule specified a compression check of the engine cylinders at 150 hour intervals, but the maintainer chose to conduct the check every 50 hours. The maintainer also opted to conduct an internal visual check of the cylinders at 50 Hour Checks for evidence of cracking, particularly in the area of the lower spark plug bore. The last 50 Hour Check was conducted 45 operating hours prior to the accident. No indications of abnormality were apparent from the records covering an extended period prior to the accident.

Background

Valve Operating Mechanism Wear

The overhaul agency carrying out the engine strip noted that camshaft and follower body distress to the extent found was quite common on engines received for overhaul, particularly those that had operated for close to the normal overhaul period. The agency estimated that approximately 70% of such engines exhibited generally similar damage, but it had not been reported that significant power loss had been associated with the condition. Similar problems had been found during other AAIB investigations. The problem appeared to have started 10 to15 years previously and to have affected both original and overhauled equipment.

The engine manufacturer estimated that the rate of occurrence of the problem found at overhaul was much lower, at an estimated 5% to 10%. Test cell results had confirmed that an engine would continue to operate apparently normally with appreciable camshaft wear present, with the only noticeable effect being reduced airflow, indicating that automatic extension of the hydraulic tappets tended to compensate for the reduction in camshaft lobe and/or follower body height. A reduction in peak power would be associated with severe wear, but this could not be quantified; at some point it would be apparent for a normally aspirated engine by virtue of a reduction in the peak rpm achievable, but would probably not be apparent from engine instruments with a turbo-charged engine. The manufacturer believed that severe wear would usually be detectable by the presence of follower body metallic debris on the oil filter element when a replaced filter was cut open for inspection. Progression of the wear was fairly rapid, probably becoming severe within one or two 50 hour oil change periods.

The engine manufacture's investigations had on no occasion identified a deviation from specification in the materials. The problem was believed to be due to spalling due to inadequate lubrication and/or the effects of corrosion occurring when the engine was operated infrequently. Inadequate lubrication was considered likely to be the result of infrequent engine operation, insufficiently frequent oil changes and/or repetitive accelerated starts (ie allowing the engine to accelerate above idle for too long on starting). It was also considered that camshaft and/or tappet regrinding during overhaul, permitted in the USA under a Supplementary Type Certificate (STC), could destroy the hardened surface layers.

A Mandatory Service Bulletin (Textron Lycoming No 446D, issued on 10 March 1999 and superseding a previous Bulletin) specified the addition of an oil additive (LW-16702) at each oil change for certain engine types (O-320-H, O-360-E, LO-360-E, TO-360-E and LTO-360-E), unless the oil already contained an equivalent additive. The valve operating mechanism for these types is similar to that for G-MAND's engine. The additive is also specified for the O-320-H and L/LO-360-E in Textron Lycoming Service Instruction (SI) No 1014M, issued 22 May 1995. The Bulletin noted that:

'Laboratory tests indicate that occasionally when the engine is first started, for a very brief interval there is insufficient residual oil between the rubbing parts which affects the service life of components. Textron Lycoming has evaluated an agent which, when added to the normal oil supply, deters scuffing under these conditions. The oil additive LW-16702, which Textron Lycoming considers essential for good engine operation, can be purchased through Textron Lycoming, Cessna Aircraft and Piper Aircraft distribution systems.'

The engine oil used for G-MAND did not contain LW-16702. The oil manufacturer noted that the additive, which is phosphorus based, is included in Aeroshell W100 Plus and W15W-50 oils. These oils include a corrosion inhibitor to counter the hygroscopic nature of the additive which could otherwise contribute to corrosion in engine types that typically run with a relatively low oil temperature. The oil manufacturer considered that W100 Plus should be suitable for the O-320 engine and would help to prevent excessive scuffing wear. However, it was considered that the prevention of wear due to accelerated starts requires starting with idle throttle and maintaining this setting for up to 30 seconds before increasing rpm to the normal idle value. The oil manufacturer's experience also suggested that failure to use the correct oil grade at the prevailing ambient temperature, as specified in SI No 1014M, could cause excessive scuffing wear during starting.

Cylinder Cracking

Information from aircraft maintenance and engine overhaul organisations indicated that cracking of cylinder heads on Textron Lycoming engines is found fairly commonly, particularly on aircraft used for pilot training, but generally at a considerably higher life than for G-MAND's cylinders. Cylinders from both the original equipment manufacturer and alternative manufacturers were affected. The engine manufacturer considered that the most likely reason for cracking at relatively low life was repetitive shock cooling and/or possibly detonation of the mixture in the cylinder. Detonation could be due to severely out of specification ignition timing, incorrect temperature range spark plugs, improper fuel, and/or carbon tracking in the magneto distributor block.

The cracks are frequently in the area of the lower spark plug hole. The aircraft maintainer considered that an appreciable crack may not be detected by a compression check, because even substantial cracks could tend to remain closed, but would generally be detected by a boroscope inspection. It was reported that two of the undamaged cylinder assemblies from G-MAND, which were salvaged undamaged after the accident and reused on another engine, were both found to have cracked within approximately 100 hours of operation.

A Service Instruction (Avco Lycoming No 1135A, issued on 12 April 1968) specified cylinder head inspection, repair and modification for all opposed series engines. It advised inspection with the aid of a fluorescent penetrant, after paint removal as the best procedure. It listed a number of areas in which cracks may be found, and noted 'Another critical area is that around the lower spark plug gasket counterbore. Cracks can progress to the point where a cylinder may fail completely. Any cracks in these areas, regardless of length or depth, are cause for rejection of the cylinder'.

Discussion

The damage to the engine valve operating mechanism found during the examination had clearly occurred before ground impact. However, such damage was not abnormal and previous experience indicated that damage to the extent found was unlikely to have caused a major power loss and would not have lead to a sudden complete loss of power. It was therefore concluded that the valve operating mechanism damage had not contributed to the power loss.

The discoloration of parts of the cylinder head fracture surfaces clearly showed that these portions of the cracks had been present while the engine had been operating and the degree of discoloration indicated their presence for an appreciable period, although this could not be quantified. Although both discoloured cracks were of considerable length, it appeared possible that they had not opened appreciably while the remainder of the section remained intact and may not have caused a substantial power loss. The slight discoloration of much of the remainder of the fracture surfaces suggested that these portions of the cracks had been present for a brief period of operation. It thus appeared that the power loss had probably resulted when a substantial pre-existing cylinder head crack had suffered a rapid, large extension around most of the head circumference, allowing the resulting crack to open up and vent the cylinder. Previous experience suggested that such a failure could cause a very substantial power loss, possibly due to disruption of the induction flow to the other cylinders. Some further extension of both cracks may have resulted from ground impact forces during the overrun.

Although in-service cracking of this type of cylinder is not uncommon, G-MAND's cylinder failure, and the reported subsequent cracking of two other cylinders from the same engine, occurred at a relatively low service life. The absence of evidence of fatigue progression of both No 1 cylinder head fractures, except in small areas of the final fracture region of the circumferential crack, suggested that the cylinder head had been overloaded. It appeared possible that this could have resulted from detonation within the cylinder but reasons for this to have occurred could not be established. With the available evidence the cause of the cylinder head failure could not be determined.

Recommendation

The severe wear of the engine valve operating mechanism was a known problem that apparently affected a substantial number of engines of different types but with similar mechanisms. There was no evidence that it had been a factor in this accident but it was clear that the wear process, once started, would continue and eventually cause a progressive loss of peak power available from the engine. The possibility that this could lead to an accident before the loss in engine or aircraft performance had been recognised could not be dismissed. It appeared that the wear problem could possibly be appreciably reduced by avoiding accelerated starts, by use of the correct grade of oil and by use of an oil additive. While the additive had been made mandatory for some engine models, there was no requirement or recommendation for its usage on the engine model involved in this accident. The engine manufacturer's SI on oil recommendations did not fully reflect the applicability of the Mandatory Service Bulletin. The following safety recommendation is therefore made:

Safety Recommendation No 2003-69

It is recommended that the FAA require Textron Lycoming to take measures to substantially reduce the incidence of excessive wear to the valve operating mechanism of the Lycoming O-320-D3G engine and all other affected engine models. Measures considered should include advising or requiring usage of the oil additive in engines not covered by Mandatory Service Bulletin No 446D, advising on engine starting procedures and re-emphasising use of the correct grade of oil for the prevailing ambient temperature.