ACCIDENT

Aircraft Type and Registration:	Jabiru UL-D, G-JAAB
No & Type of Engines:	1 Jabiru Aircraft Pty 2200B piston engine
Year of Manufacture:	2006
Date & Time (UTC):	12 September 2007 at 1541 hrs
Location:	Upper Dean, 10 nm north of Bedford, Bedfordshire
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - 1
Injuries:	Crew - None Passengers - None
Nature of Damage:	Landing gear and left wing damaged
Commander's Licence:	National Private Pilot's Licence
Commander's Age:	39 years
Commander's Flying Experience:	175 hours (of which 131 were on type) Last 90 days - 34 hours Last 28 days - 18 hours
Information Source:	AAIB Field Investigation

This investigation was conducted in parallel with the investigation into G-CEED, also published in this AAIB Bulletin, 5/2010.

Synopsis

Approximately two hours into the flight the pilot noticed the sudden onset of vibration. He reduced the engine power, which reduced the vibration but the aircraft was unable to maintain altitude. He made a MAYDAY call to ATC and during the approach to a field the engine stopped. During the landing roll the nosewheel dug into soft ground, causing the aircraft to turn right and come to a rapid halt. Examination of the engine revealed that the No 3 cylinder exhaust valve had failed in fatigue and the remaining three exhaust valves had fatigue cracks in the same area. The engine had operated for 121 hours since manufacture and had the changes in Jabiru Service Letter JSL 002-1, '*Jabiru Engine Economy Tuning',* embodied.

During this investigation, items from another, similar, Jabiru 2200 engine, fitted to a Thruster microlight, G-CBIP, were examined following a failure of No 1 cylinder exhaust valve. The metallurgical examination of all four exhaust valves indicated a failure mode and fatigue cracking very similar to those from G-JAAB. The engine had operated for approximately 300 hours since the valves were replaced and had the changes in Jabiru Service Letter JSL 002-1 titled '*Jabiru Engine Economy Tuning'* embodied.

History of the flight

The pilot/owner carried out a full pre-flight inspection which included topping up the engine oil and filling the fuel tank with 100/120LL Avgas. A full tank gave approximately 5 hours endurance. The pilot flew an uneventful flight from Rochester to Manchester Barton where he refuelled the aircraft, again filling the tank, with Avgas. After approximately an hour on the ground at Barton the pilot returned to the aircraft, carried out a pre-flight inspection, started the engine and departed back to Rochester. Approximately two hours after departing from Barton the pilot felt a sudden vibration from the engine. He reduced power and the vibration reduced and he was able to maintain 1,800 rpm with moderate vibration. The pilot made a PAN call to Cranfield ATC, reported what had happened and that the aircraft was unable to maintain altitude. He also set the transponder code to 7700. Cranfield ATC asked the pilot if he intended to land at an airfield but as the aircraft was descending through 1,000 ft amsl, and there was a built-up area to transit to the nearest airfield, he decided to carry out a forced landing in a suitable field.

After declaring a MAYDAY the pilot noticed a large helicopter circling what appeared to be a grass strip suitable for microlight aircraft. He made an approach to the apparent microlight strip but soon realised that it was not long enough for a safe landing and instead opted for a nearby large ploughed and tilled field. During the approach the engine stopped. Touchdown was at a normal aircraft attitude but on a piece of rough ground. As the airspeed reduced the nosewheel dug into the soft ground, causing the aircraft to turn to the right and the left wing to contact the ground. The aircraft rapidly came to a halt and settled onto all three landing gears. The pilot turned off the electrics and fuel before exiting the cockpit. After establishing that there was no fire or fuel leak he re-entered the cockpit, turned on the electrics and attempted to make radio contact with Cranfield ATC to inform them of his position and that he was uninjured. Although he could hear Cranfield they could not hear him. Eventually another aircraft, that was airborne, acted as a relay.

Engine description

The Jabiru 2200 is a four-stroke horizontally-opposed four cylinder piston engine, normally aspirated and air cooled. The displacement is 2200 cc which produces nominally 85 hp at 3,300 rpm. The fuel specified is either Avgas 100/130 (preferred) or Mogas with an octane rating of 95 or above. The carburettor is pressure compensated and is mounted to a plenum chamber in the sump casing by a flexible rubber coupling. From the plenum chamber the fuel/air mixture is delivered to the cylinders via individual inlet pipes. There is no fuel mixture control in the cockpit. The fuel/air mixture is set up during manufacture, installation or maintenance. There is one cylinder head temperature sensor, mounted under the No 4 cylinder spark plug, which is connected to a gauge in the cockpit.

The engine is fitted to a wide range of manufactured and home built Light Sport Aircraft worldwide.

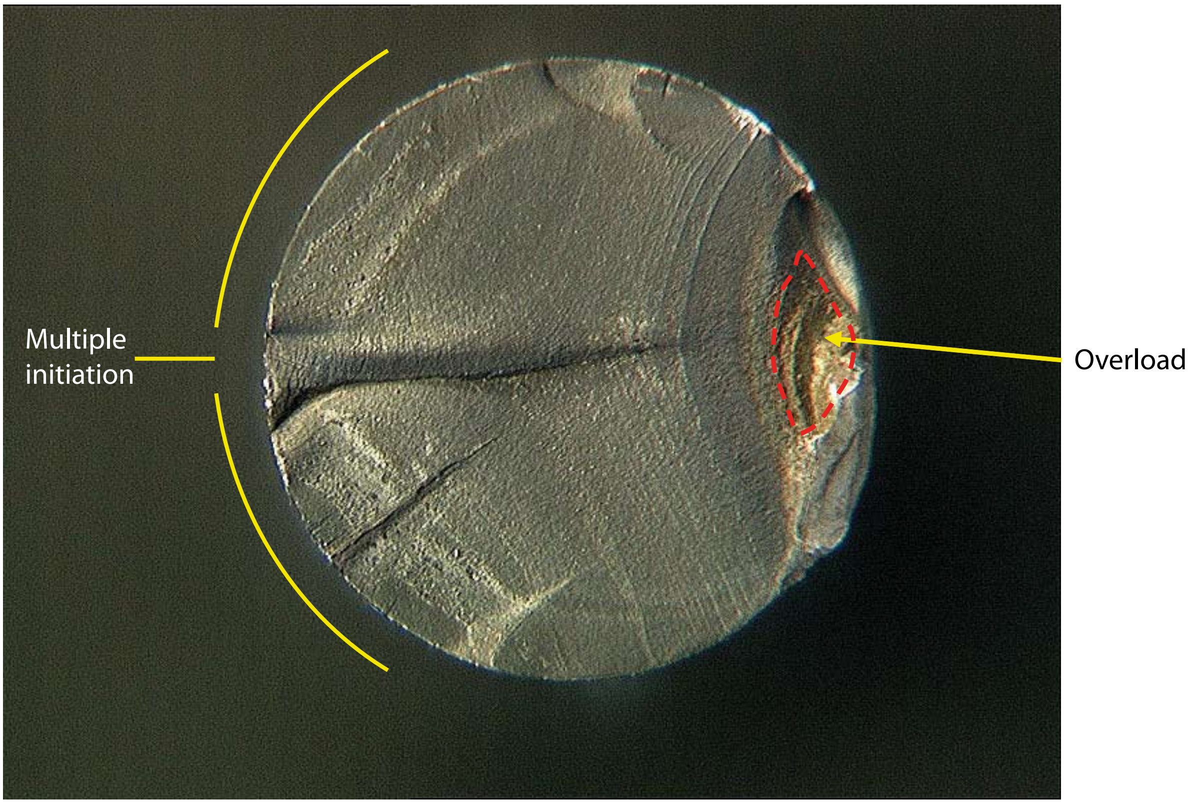
Engineering examination – G-JAAB

The engine was taken to the manufacturers' UK agent for strip examination. This examination revealed that the head of the No 3 cylinder exhaust valve had broken away from the valve stem. The cylinder heads and their inlet and exhaust valves were taken to QinetiQ for detailed metallurgical examination.

Examination of the No 3 exhaust valve showed that the fracture occurred in the stem of the valve adjacent to the head radius. It was noted that the stem-side fracture was coated with a dark deposit unlike the head-side, which was relatively clean. Detailed examination of the stem-side deposit under high power optical microscopy revealed the presence of bright discrete globular metallic particles amongst the deposit. The particles were soft and could be smeared, which suggested that they could be particles of lead. After cleaning, the fracture surface of the stem side was examined and seen to exhibit beachmarks, which are characteristic of failure due to fatigue crack growth (Figure 1). Multiple fatigue crack initiation sites were present around the majority of the valve circumference, although crack growth appeared to have been predominantly from one side of the valve. A small area of overload was present at the end of the fatigue.

Visual examination of the remaining section of the exhaust valve stem revealed secondary cracking adjacent to the fracture surface (Figure 2).

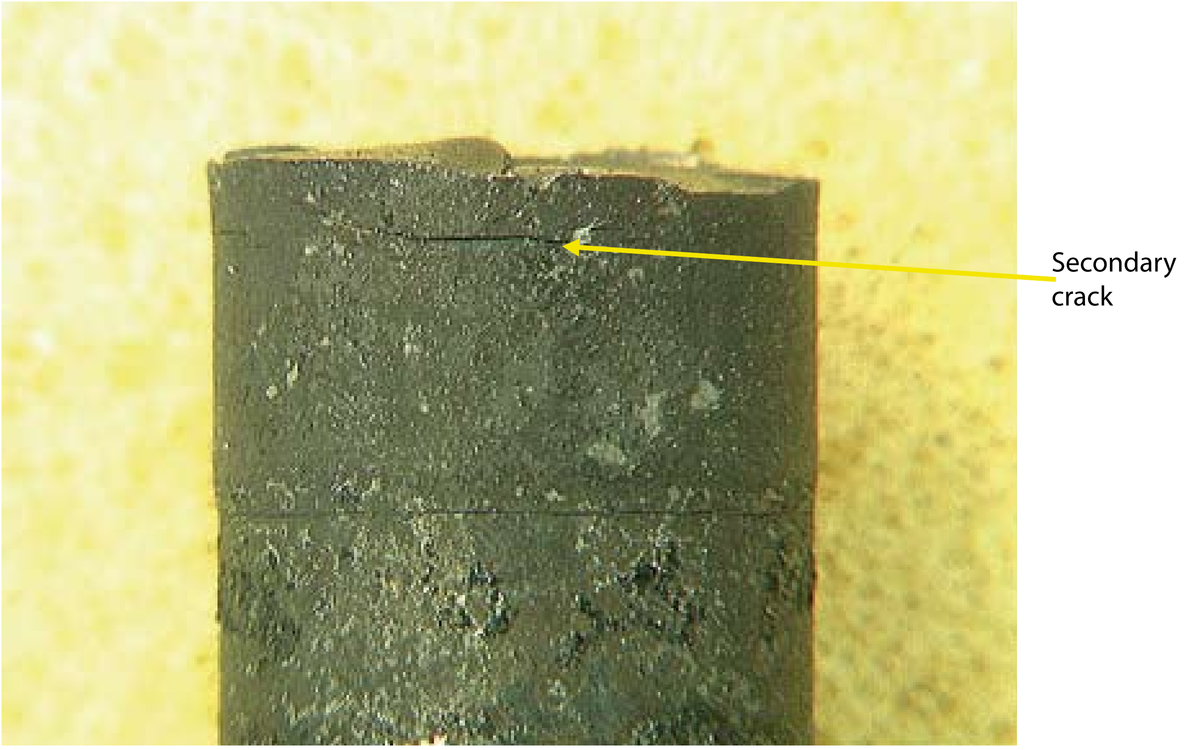
Examination of the cylinder head showed extensive mechanical damage on the internal surface caused by repeated impacts of the head of the exhaust valve after detachment from the stem; this pattern of mechanical damage was also observed on the piston crown. Detailed examination of the exhaust port on the cylinder head showed evidence of globular metallic particles similar to those observed on the fracture surface of the exhaust valve.



Courtsey of QinetiQ

Figure 1

Fracture surface of No 3 exhaust valve from G-JAAB after cleaning



Courtsey of QinetiQ

Figure 2

Stem of No 3 exhuast valve from G-JAAB adjacent to fracture showing secondary cracking

Exhaust valves 1, 2 and 4 exhibited small transverse cracks (Figure 3) at the edge of the head radius, in a position similar to the fracture point of the exhaust valve from cylinder No 3, indicating that all the cylinders had experienced similar high temperatures.

Energy dispersive X-ray (EDX) analysis was carried out in a scanning electron microscope (SEM) on the fracture surface of the No 3 exhaust valve prior to cleaning to determine the composition of the deposit. The EDX spectrum identified elements such as iron, manganese and chromium from the underlying valve steel. However, large amounts of lead, phosphorus and bromine were present, with carbon and oxygen. A metallurgical section of the valve stem was subjected to EDX analysis and the spectrum obtained was consistent with 21-4N valve steel. The SEM examination showed that the microstructure was typical of a 21-4N valve steel, showing an austenitic[1] microstructure structure containing carbide stringers[2]. Adjacent to the failure area, secondary cracking was observed. Corrosion was observed on the surface of the stem and the microstructure showed evidence of grain boundary precipitates[3].

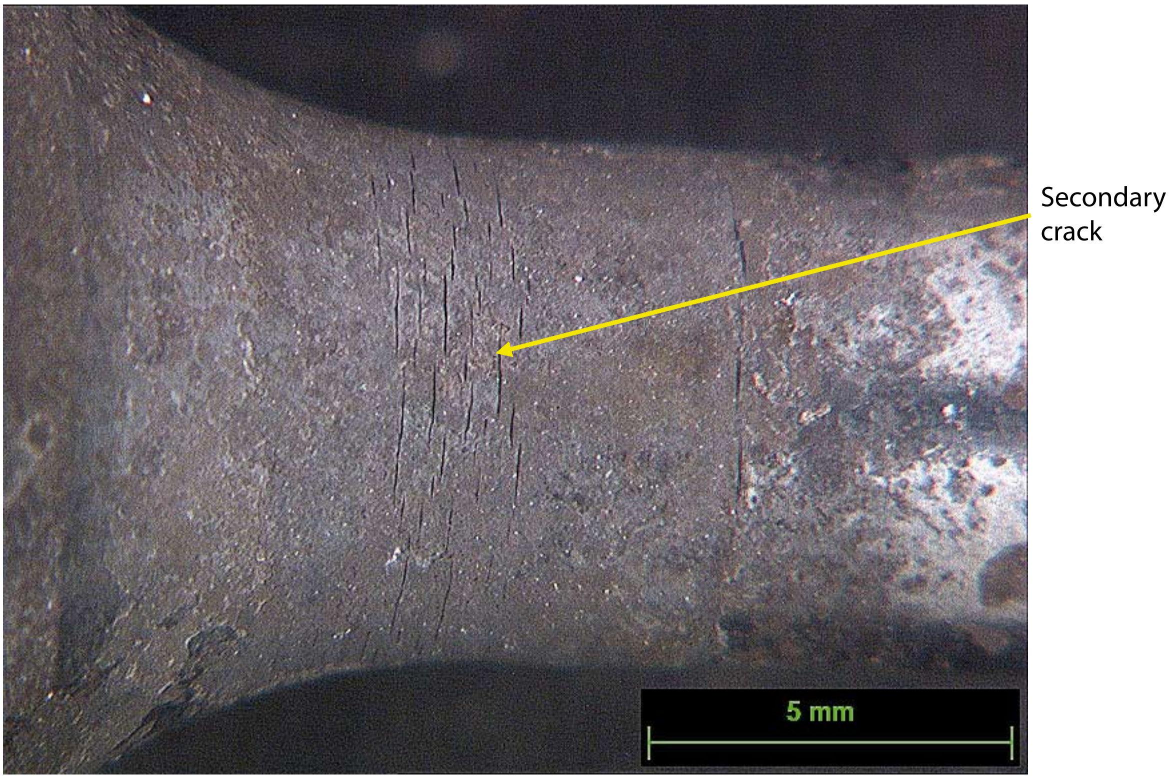
Hardness testing was carried out at a number of points on the No 3 exhaust valve and all values were above the specified minimum hardness for 21-4N material.

Footnote

1 A nonmagnetic solid solution of ferric carbide or carbon in iron, used in making corrosion-resistant steel.

2 Carbide stringers are chain-like rows of carbide precipitates (formed from combination of a metal + carbon) that are stretched out in the direction of working.

3 Grain boundary precipitation is the result of diffusion within the material, the rate of which is controlled by time and temperature. As temperature increases, the rate of diffusion increases and grain boundary precipitation occurs within a shorter time period.



Courtsey of QinetiQ

Figure 3

No 4 cylinder exhaust valve from G-JAAB showing secondary cracking

Other information – G-JAAB

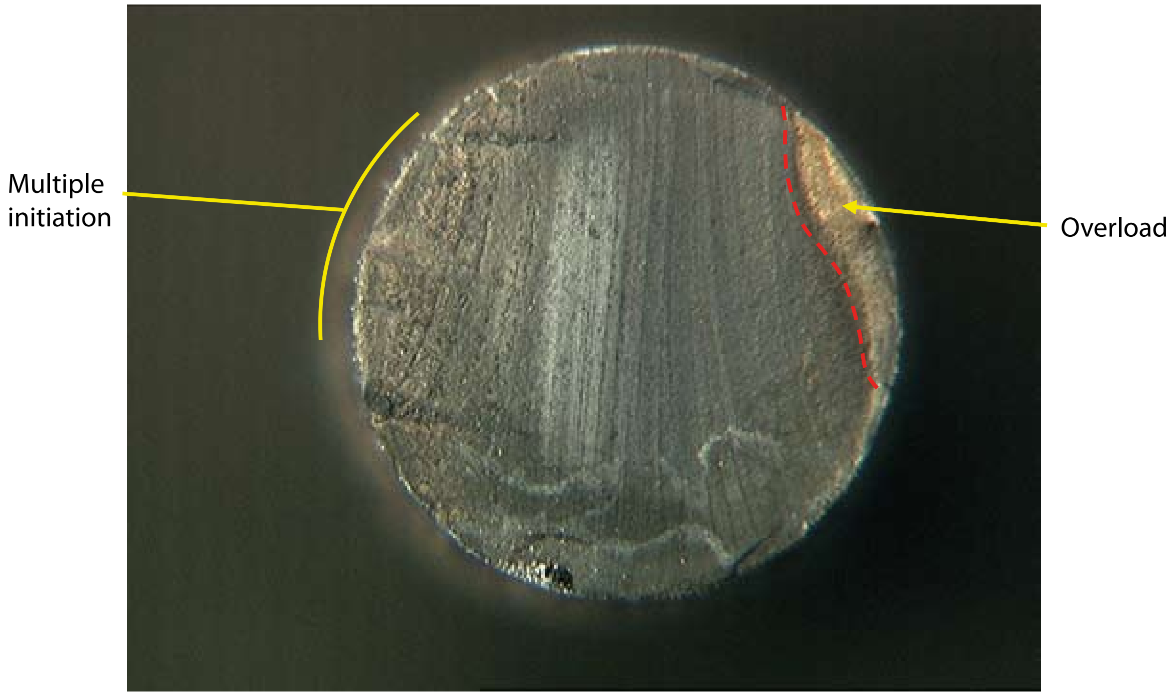
The engineering examination did not show any indication of significant leaks at the cylinder head seals, inlet or exhaust systems and no restriction within the engine oil supply system. The engine had a total of 121 hours in use since it was installed into the aircraft as a new unit and had a 100-hour maintenance check carried out in August 2007 in accordance with the manufacturers' requirements.

The engine was found to have been configured in accordance with Service Letter JSL 002-1 titled '*Jabiru Engine Economy Tuning'* which was issued in December 2004. The owner stated that the engine had only been run using 100 LL Avgas.

Failure of exhaust valve from G-CBIP

During the investigation of the exhaust valves from G-JAAB, the No 1 cylinder head and piston from another Jabiru 2200 engine, fitted to a Thruster T600N microlight G-CBIP, was taken to QinetiQ for examination. The cylinder head contained the inlet valve and the fractured stem of the exhaust valve: the head of the fractured valve was embedded in the piston crown. It was reported that this engine had run for approximately 300 hours. The three other exhaust valves were also examined.

The cylinder head exhibited extensive mechanical damage on the internal surface caused by repeated impacts by the head of the exhaust valve after detachment from the stem, similar to that in G-JAAB. As with G-JAAB, the fracture surface was covered with a dark deposit and globular metallic particles were present



Courtsey of QinetiQ

Figure 4

Fracture surface of No 1 exhaust valve from G-CBIP

within the exhaust port. Figure 4 shows beachmarks clearly visible on the fracture surface, characteristic of fatigue crack growth. The fatigue appeared to have initiated from multiple points on one side of the valve and propagated across the majority of the valve stem before final overload failure occurred.

Examination of the stem surface adjacent to the fracture showed evidence of multiple secondary cracking (Figure 5) similar to that observed in G-JAAB.

Examination of the three remaining exhaust valves from G-CBIP showed two of the three valves exhibiting small transverse cracks at the edge of the head radius, in a position similar to the fracture point of the exhaust valve from the No 1 cylinder. The cracking was similar to the secondary cracks observed in G-JAAB.

EDX analysis carried out on the fracture surface of the No 1 exhaust valve showed a spectrum similar to the deposit on the No 3 exhaust valve of the engine from G-JAAB, with large deposits of lead and bromine and some phosphorus. The lead and bromine were consistent with combustion products of 'anti-knock', and other, agents in Avgas fuel.

This engine had also been configured in accordance with Service Letter JSL 002-1 '*Jabiru Engine Economy Tuning*' and the owner stated that the engine had been run on both Avgas and Mogas of 95 octane rating and above (approximately 150 hours on each).

Other information and further valves

An intact exhaust valve, removed from a Jabiru 2200 engine during a 1,000-hour maintenance check, was sectioned longitudinally and polished to reveal the microstructure. It was seen that at the base of the stem, the location of the failures and secondary cracking in the valves from G-JAAB and G-CBIP, the material 'etched' differently from further up the stem, indicating

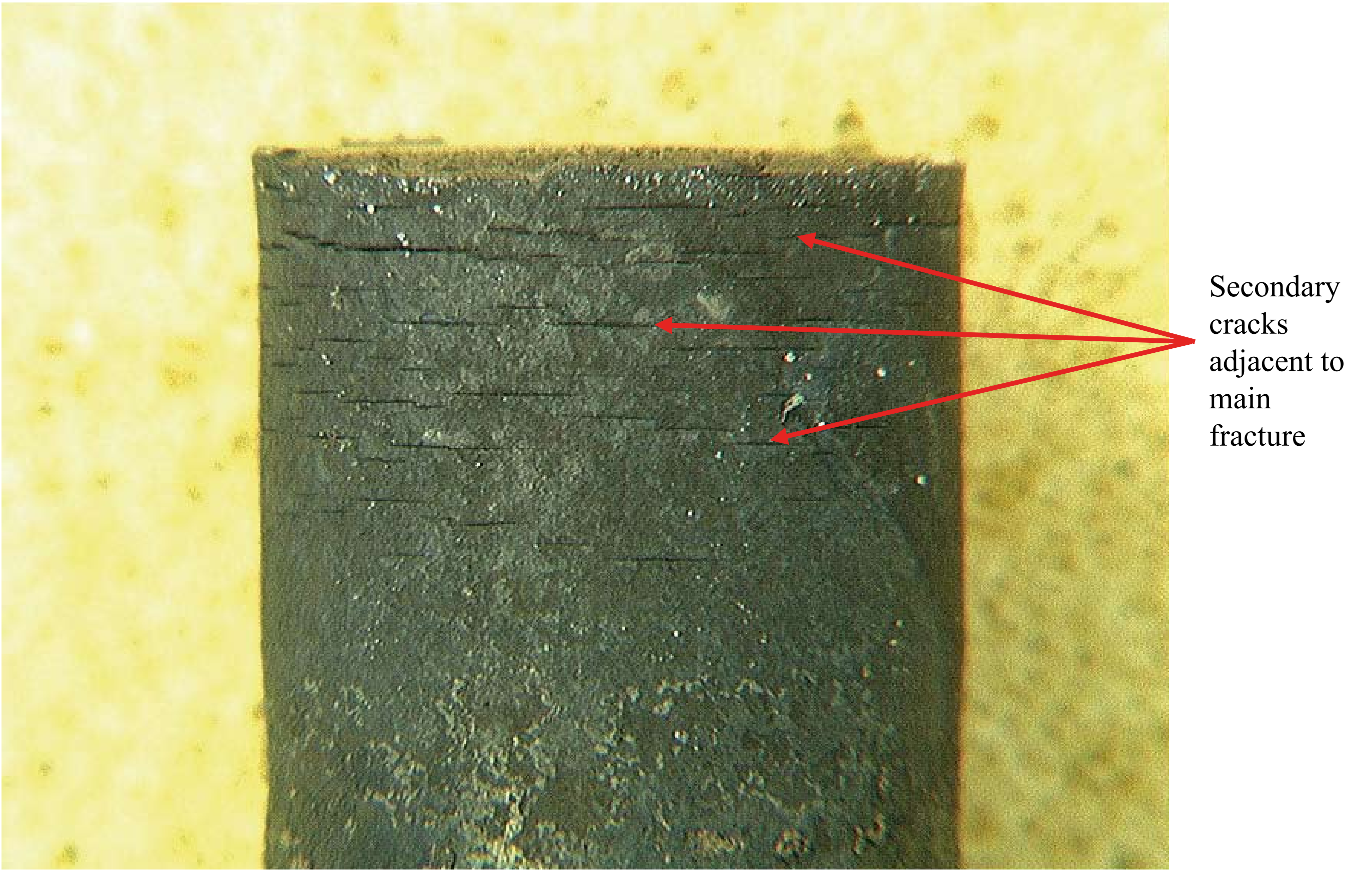


Figure 5

Secondary cracking in the failed No 1 cylinder exhaust valve stem from G-CBIP

a change in microstructure in this area. The area at the base of the stem showed evidence of extensive grain boundary precipitation, similar to G-JAAB and G-CBIP. Examination at the base of the stem identified two small cracks emanating from corrosion pits at similar positions on opposite sides of the stem, cracks in a similar position to the failures in the valves from G-JAAB and G-CBIP.

A new exhaust valve, supplied by the valve manufacturer, was sectioned longitudinally and examined. The microstructure showed an austenitic grain structure containing carbide stringers similar to the general microstructure of the upper stems of the exhaust valves fitted to the engines from G-JAAB and G-CBIP. At the base of the stem there was some grain growth apparent, but no evidence of the grain boundary carbides seen in the failed and 'used' valves. The microstructure appeared typical of an as-forged 21-4N component.

The typical maximum operating temperature for 21-4N valve steel is in the region of 725-750°C and the microstructures of the failed exhaust valves were discussed with the valve manufacturer. From their experience, they considered that the premature grain boundary precipitation observed in the failed valves indicated that they had been operating in the region of 750-800°C, although this operating temperature could not be verified as no aging or precipitation information could be found for this particular material.

Jabiru Service Letter JSL 002-1

Jabiru JSL 002-1 was issued on 13 December 2004, titled '*Jabiru Engine Economy Tuning'* which introduced the '*Economic Tuning Kit'*. This kit contained new idle, needle and main carburettor jets, a new needle and fitting instructions. This Service Letter introduced 'lean burn' jets into the carburettor to improve fuel consumption at cruise power.

Jabiru Service Bulletin JSB 018-1

Jabiru JSB 018-1 was issued on 5 October 2007, titled '*Jabiru Engine Tuning*'. The Service Bulletin introduced richer running jets into the carburettor to replace those introduced by Service Letter JSL 002-1.

Discussion – G-JAAB and G-BCIP

Examination of the two failed exhaust valves showed in both cases that failure was a result of fatigue crack propagation initiating at multiple origins at the base of the exhaust valve stems. Examination of the valve stem surfaces in the regions of failure identified pitting and general surface corrosion, with secondary cracking. The fatigue cracking probably initiated from corrosion pits on the surface of the stems, which would act as stress concentrators. Examination of the intact valves also showed evidence of corrosion and cracking.

Metallographic examination of the new exhaust valve showed that the microstructure was austenitic with carbide stringers through the grains, typical for 21-4N valve steel. Examination of the failed valves showed a similar microstructure to this 'new' valve towards the stem tip, but closer to the region of failure, the microstructure exhibited grain boundary carbide precipitation along with a lamellar structure within the grains. The degree of grain boundary precipitation increased as the failure location was approached until, at the point of failure, the microstructure exhibited an extensive network of grain boundary precipitates.

Examination of the microstructure of the intact '~1,000 hrs' valve showed evidence of grain boundary precipitation along the length of the stem, not just at the base, which suggests that, at 'typical' operating temperatures, diffusion after approximately 1,000 hours is sufficient to cause grain boundary precipitation along the length of the stem. The failed exhaust valves exhibited grain boundary precipitation at the base of the stem after much shorter periods of time (lowest 120 hours), which suggests that the temperature of the exhaust valve at the base of the stem must have been higher than 'typical'. It is accepted that the base of an exhaust valve stem generally experiences the highest temperatures within a piston engine. Therefore, it is expected that microstructural changes will occur first at the stem base, the hottest part of the valve. However, failures occurring after as little as 120 hours suggests that, in those instances, the exhaust gas temperature was higher than 'typical' - that the engines were running hot and the exhaust valves were overheating.

Grain boundary precipitation and lamellar growth within the grains produces a microstructure that is more susceptible to corrosion in 21-4N valve steel and increased temperature increases the corrosion rate. Therefore, increased exhaust gas temperature increases the temperature at the base of the valve stem, which increases the diffusion rate and hence the rate at which the microstructure changes. The changed microstructure, which is more susceptible to corrosion along with the increased temperature of the exhaust gas, which is itself more corrosive, combine to cause premature corrosion of the exhaust valves, which leads to fatigue crack initiation and eventual failure.

In summary, the evidence from these valve failures indicates that overheating of the valves was at least a contributory factor and this was consistent with the timing of Jabiru JSL 002-1, which introduced 'lean burn' jets into the carburettor to improve fuel consumption at cruise power. However, Jabiru JSB 018-1, issued in October 2007, introduced richer running jets into the carburettor to replace those introduced by Service Letter JSL 002-1.

Safety action

Following the failures of a number of Jabiru 2200 engines in the UK (including G-CEED (10/07), G-CEFY (2/08) and G-JAAB (9/07)) the AAIB informed the engine manufacturer. A number of overheat-related failures occurred in France at about the same time. The engine manufacturer has a continuing programme of product quality improvement and the number of such events reported to the AAIB and the LAA (Light Aircraft Association) has decreased since that period.