Aircraft Type and Registration:	Grob G115E Tutor, G-BYXJ
No & Type of Engines:	1 Lycoming AEIO-360-B1F piston engine
Year of Manufacture:	2001
Date & Time (UTC):	29 June 2004 at 1650 hrs
Location:	4.5 nm Southwest of Salisbury, Wiltshire
Type of Flight:	Training
Persons on Board:	Crew - 2 Passengers - None
Injuries:	Crew - Nil Passengers - N/A
Nature of Damage:	One propeller blade, part of propeller hub and canopy detached; substantial damage to engine and airframe
Commander's Licence:	Royal Air Force Qualified Flying Instructor
Commander's Age:	28 years
Commander's Flying Experience:	1,450 hours (of which 215 were on type) Last 90 days - 60 hours Last 28 days - 20 hours
Information Source:	AAIB Field Investigation

Synopsis

The aircraft was completing an aerobatic manoeuvre when one of the propeller blades separated from the hub. Despite severe vibration, the pilot was able to shut down the engine quickly and perform a successful forced landing in a field. There were no injuries to either crew member.

The investigation determined that the No 1 propeller blade had detached due to a high-cycle fatigue failure of the blade socket in the aluminium alloy hub. The pattern of cracking suggested that the failure may have been vibration related. It was also established that the propeller blade-retaining nut preload decreases rapidly in the first few hours of propeller operation, raising concerns that the reduction in blade retention stiffness could increase the blade's propensity to vibrate, thereby increasing the stresses in the hub. A safety recommendation concerning the need for further vibration testing to be carried out in order to fully understand the mechanism of the failure was made on 1 December 2004. Two further safety recommendations have also been made concerned with the continued airworthiness of the propeller and focusing on propeller blade retaining nut maintenance procedures and the non-destructive testing of propeller blade sockets to detect fatigue cracks.

Background information

The aircraft was operated by the RAF University Air Squadron (UAS) based at RAF Boscombe Down, Wiltshire, England. The aircraft commander was a military flying instructor and the student was a member of the UAS undertaking a navigation training course. All of the Grob G115E Tutor aircraft operated by the UAS are on the UK civil aircraft register and were supplied by a civilian organisation which also holds a JAR-145 approval for maintenance. Crews flying the aircraft are subject to the UK Air Navigation Order.

History of flight

The aircraft was carrying out a short sequence of aerobatic manoeuvres at the end of an uneventful navigation training exercise. The weather was fine with a surface wind of 210°/12 kt, visibility of 35 km with a few clouds at 2,300 feet and broken cloud at 25,000 feet.

After a climb to FL50, using high RPM and full power, the instructor completed the 'HASELL' checks, selected 2,500 RPM and confirmed that the auxiliary fuel pump was OFF and that the fuel was balanced between the two wing tanks. After a clearing 'Wing Over' to the right the aircraft completed a loop at 130 kt, flew level briefly and then entered a '1/2 Cuban', climbing with a 60º nose-up attitude. When the airspeed reduced below 100 kt, full back control column and full left rudder was applied. The aircraft entered a snap roll (dynamic spin) to the left through 180° and was stabilised inverted in the climb before being 'pulled through' to the horizon.

As the aircraft levelled, at approximately 120 kt with full power still set, there was a loud bang accompanied by extreme vibration. The instructor saw debris passing the canopy and could feel airflow entering the cockpit. His immediate thought was that his aircraft had been involved in a mid-air collision. As he transmitted a 'MAYDAY' call he was aware of the canopy moving backwards and then detaching; neither occupant had touched the canopy latching system. The instructor could see that the propeller blades were damaged but the resultant vibration was such that he could not read the cockpit instruments. As the engine was shut down, the vibration increased but then stopped. When the propeller blades were stationary, it was possible to see that one appeared to be missing and one was badly damaged. Oil was also visible on the right windscreen.

The instructor had initially considered abandoning the aircraft but with the vibration stopped he now elected to carry out a forced landing. He was familiar with the area and able quickly to identify a suitable field that he had used previously in practice exercises. Passing through his planned 'High

Key' position, he completed his 'Forced Landing' checks and informed ATC of his present position and intention to land. The aircraft touched down, in a field in standing crop, at approximately 60 kt. On the ground, the nose started yawing to the right and the aircraft began sliding to the left. The nose landing gear was damaged, the left gear collapsed and the aircraft came to rest after a ground roll of about 50 metres. The crew were uninjured and able to vacate the aircraft without difficulty.

Subsequently, a coastguard helicopter transported the crew to Salisbury Hospital for medical checks.

Prior to flight the instructor had checked the Technical Log and signed for the aircraft. He noted that there were no outstanding defects in the Log and that the aircraft was fully refuelled. During his pre-flight exterior check, the instructor recalled visually checking the propeller and associated area and noted nothing unusual.

Aircraft examination

The aircraft had landed in a cornfield and was intact, except for the canopy, the No 1 propeller blade and a section of the propeller hub, which were missing. It was evident that the No 1 propeller blade had detached due to a fracture of the blade socket of the aluminium alloy hub (Figure 1). The fracture, which appeared to originate in the threads inside the blade socket, allowed the outer part of the blade socket and the blade retaining nut to separate from the hub, thus releasing the propeller blade. The departing blade was struck by the following (No 3) blade, causing the detachment of a large portion of the latter (Figure 2).

The canopy, the No 1 propeller blade and the detached section of the hub blade socket were located approximately 3.5 km from where the aircraft had landed. The latching mechanism of the canopy was still in the locked position and it was apparent that the severe vibration from the propeller imbalance had caused the canopy to detach from the aircraft.

The vibration had also caused significant damage to the engine and its mountings. The left-hand upper mounting lug had severed from the engine crankcase and the engine support frame was cracked and distorted, causing the engine assembly to rotate downwards through an angle of about 10°. The left-hand magneto had come away from its mounting and both exhaust mufflers had severed from the exhaust down pipes at the welded joints. The fuel flow gauge had also detached from the instrument panel.

There was no evidence of the aircraft having suffered a bird strike or collision with any other object.

Immediate safety actions

The maintenance organisation responsible for supplying and maintaining the aircraft withdrew the Grob G115E Tutor from operation immediately after the accident.

In July 2004 the propeller manufacturer issued Service Bulletin 61-10-03 SB E 15. This required propeller disassembly for eddy current non-destructive testing (NDT) to check for cracks in the threads of the propeller blade sockets prior to further flight. The Service Bulletin was mandated by the German Luftfahrt Bundesamt (German Civil Aviation Authority) under EASA-approved Airworthiness Directive LTA D-2004-352R2.

Aircraft with propellers that passed inspection were returned to service, but were subject to a regime of checking the propeller blade retaining nut torque values at intervals of 5, 25, 50, and 100 flying hours. In addition, an eddy current crack check of the blade socket threads was required every 100 flying hours. This also required the propellers to be disassembled.

A total of 26 hubs were rejected following the initial eddy current inspection. These were returned to the propeller manufacturer for examination, the results of which are still awaited. Hub, serial number G23, exhibited a particularly large amplitude eddy current defect indication in the bottom thread of the No1 blade socket and was initially examined by the AAIB, prior to being returned to the manufacturer. The serial number of the hub on G-BYXJ was G22.

Propeller information

The Grob G115E is fitted with a Hoffmann HO-V343K-V/183GY three-bladed constant-speed propeller (Figures 3 & 4). The hub is manufactured from forged aluminium alloy and the Type 183GY propeller blades are manufactured from compressed hardwood and spruce, with an outer sheath of carbon fibre. Each blade is mounted in a duralumin carrier, or ferrule. The blade is attached to the ferrule by large screws, that screw into the compressed hardwood blade root. The ferrule locates into a socket in the propeller hub. Needle roller bearings transmit blade centrifugal loads to the hub and allow the blade to rotate in pitch. The propeller blade is secured in the hub by a blade retaining nut, which screws into the threaded blade socket and is torque-tightened to between 30 and 40 Newton-Metres (Nm). A 'T-shaped' locking plate prevents the nut from rotating.

The maximum approved operating speed of the propeller is 2,700 RPM. Typical propeller speed during takeoff is 2,700 RPM and the speed in cruising flight is typically between 2,300 and 2,500 RPM. In February 2004, however, the aircraft manufacturer issued Service Letter No SIL115-50 recommending that the engine should be operated at 2,400 RPM or below whenever possible; the high vibration levels found to be present above 2,400 RPM having a detrimental effect on engine ancillary components.

Propeller design

The design requirements for aircraft propellers, specified in JAR-P Section 190, state that:

> *'A test shall be conducted on prototype propellers with detachable wooden blades to determine that the vibration characteristics are not such as to cause resonance detrimental to airworthiness throughout the whole range of speeds up to the Maximum Permissible Rotational Speed'.*

Design certification tests performed by the propeller manufacturer on the G115E propeller, in isolation, did not identify any vibration or resonance problems. It is understood that the aircraft manufacturer chose not to perform vibration testing on the engine-airframe-propeller combination as it was not considered necessary. A vibration survey had previously been completed on the Grob G115D variant, which has the same engine as the G115E and a Hoffmann HO-V 343K( )-V/180FP three-bladed constant speed propeller, which is similar to the propeller of the G115E. Both shared the same hub, but the propeller blades differed in airfoil design and span. A natural frequency analysis performed on both propeller blades showed the resonant frequencies to be largely the same. The vibration survey on the G115D and the comparable blade natural frequency analysis results were used to demonstrate compliance with the design requirements on the G115E, thus precluding the need for separate tests. (A vibration survey involves flight testing the aircraft with strain gauges installed on the airframe and propeller, to enable the magnitude of vibratory stresses to be measured.) One notable difference between the two aircraft is that the G115D has a glass fibre reinforced plastic airframe, whereas the G115E airframe is constructed of carbon fibre.

Following the G-BYXJ accident, the propeller manufacturer re-evaluated the stresses on the blade socket of the hub during the particularly high propeller loading conditions present in a snap roll manoeuvre. These calculations suggested that the stress levels induced in the propeller hub during such a manoeuvre were not critical.

The HO-V343K-V/183GY propeller is of a generally similar design to other propellers produced by this manufacturer and this is the first occurrence of a hub failure on this propeller type.

In-service experience

The G115E has been in service for approximately five years and the highest time propeller has achieved approximately 2,400 flying hours to date.

According to the maintenance organisation, service experience on the G115E has shown that engine components including the left-hand magneto, starter motor, timing and idler gears and exhaust mufflers exhibit an unusually high failure rate. The failures are believed to be attributed to the high vibration levels experienced on the aircraft. Measurements taken by the propeller manufacturer on a G115E aircraft using an HO-V343-K-V/183GY propeller, and a propeller from another manufacturer with a similar polar moment of inertia, showed that the levels of torsional vibration increase significantly at engine speeds above 2,500 RPM. This has the effect of inducing high oscillatory torque loadings which are transmitted to the propeller. This is thought to be associated with a crankshaft torsional resonance condition that occurs at around 2,600 RPM. An independent study conducted by the engine manufacturer showed that the left-hand magneto also experienced increased levels of torque vibration at engine speeds above 2,500 RPM. The vibration issues prompted the aircraft manufacturer to issue Service Letter No SL115-50 recommending that the engine be operated at 2,400 RPM or below, whenever possible.

According to the maintenance organisation, the removal rate of the G115E propeller is high compared to other propellers, with nearly 400 unscheduled removals on a fleet of 99 aircraft since the G115E entered service with the RAF in late 1999. The reasons for the unscheduled removals included foreign object damage to the blades, cracking of the blade ferrules and blade tip play.

A review of overhaul records for these propellers showed that a significant number were found to have blade retaining nut torque values below the propeller Component Maintenance Manual lower limit of 30 Nm on disassembly.

Propeller maintenance requirements

The aircraft was maintained by the JAR-145 approved maintenance organisation in accordance with Approved Maintenance Schedule 'VTAE/Grob 115 Series', that was compiled by the maintenance organisation based on the manufacturer's recommendations and approved by the UK CAA. The propeller is inspected daily during each Check 'A' and at each '50 Hour' aircraft inspection. The Check 'A' inspection requirements include an inspection of the propeller and spinner for damage. This includes a check for blade tip play, referred to as 'tip rock' or 'blade shake'. The method, as demonstrated by an engineer from the maintenance organisation, is to apply force at the blade tip in the fore/aft and sideways directions in turn, whilst feeling for any detectable movement at the blade root.

The manufacturers 'HO-V343-( ) Propeller Operation and Maintenance Manual (E492)' requires the propeller to be inspected daily, in accordance with the following instructions:

> *'7.1 Daily Inspection*
>
> *Check blade installation.* ***No*** *blade shake is allowed. Blade angle play up to 1° is permitted. Check the propeller for loose screws and safety wires, the blades and the propeller spinner for damage. Turn blades by hand to check for smooth pitch change. Check the correct position of counterweights, if installed.'*

It was noted that these instructions do not include any illustrations depicting blade shake or how it should be detected. Blade 'angle play' denotes blade rotational movement in the pitch change sense.

The aircraft manufacturer's Maintenance Manual for the Grob G115E requires that the propeller be inspected every 50 flying hours with the spinner removed. This includes a visual inspection of the propeller for oil leaks and damage to the blades and spinner. It also includes a requirement to refer to the propeller manufacturer's operating and maintenance instructions.

Service experience has shown that cracking of the blade ferrules can occur and the blade counterweights can rotate away from their set position. Consequently, in April/May 2004 the maintenance organisation issued 'Maintenance Instruction No 49/04' to inspect the blade ferrules every 25 flying hours with the spinner removed, and 'Maintenance Instruction No 45/04' to check for counterweight rotation at each spinner removal.

The Technical Log showed the next scheduled inspection on G-BYXJ as being due at 1,284:35 flying hours, which included an inspection of the blade ferrules. This was overlooked by the engineers from the maintenance organisation, by the aircraft commander on the accident flight and by the aircraft commander on the previous flight. The aircraft had completed 1,284:50 flying hours immediately prior to the accident flight. The inspection had actually been due at 1,284:55 flying hours, but a minor slip made when transposing the figures from one Technical Log sheet to another showed it being due at 1,284:35 hours.

Propeller overhaul requirements

The manufacturer's specified overhaul life of the propeller is 1,600 flying hours or 7 years, whichever occurs soonest.

The Component Maintenance Manual (CMM) E661, for the HO-V343-( ) series of propellers contains a general requirement that all steel and aluminium parts of the propeller be inspected for cracks when the propeller is overhauled. Aluminium parts, such as the hub, are required to be NDT inspected either by a fluorescent or a non-fluorescent dye penetrant method. There are no detailed instructions for inspecting any of the individual propeller components.

The JAR-145 approved UK overhaul agency inspects the threads in the blade sockets for cracks at propeller overhaul using the fluorescent dye penetrant method, which is approved by the propeller manufacturer. According to NDT experts consulted, this is not the most reliable technique for detecting cracks in threads, because of the tendency of the dye penetrant to pool in the roots of the threads, potentially masking any crack that might be present. Furthermore, given the relatively small diameter of the blade socket, a mirror is required to inspect the threads, making this a labour intensive inspection.

Examination of G-BYXJ's propeller

The damaged propeller from G-BYXJ (serial No G22) was initially examined by the AAIB, prior to being submitted for expert detailed metallurgical examination. During disassembly it was noted that the breakaway torque required to undo the No 2 blade retaining nut was only 16.7 Nm; well below the lower limit of 30 Nm quoted in the propeller Component Maintenance Manual.

Dimensional measurements of the No 1 blade components, including the pitch change bearings and thrust washers and the pitch change bush, which is pressed into the hub, showed that the levels of wear were not excessive. A red/brown residue was found on the pitch change roller bearings which appeared to be indicative of fretting between the rollers and the races.

Metallographic examination, chemical analysis and mechanical tests of the hub revealed a fine-grained forged microstructure and both the material composition and strength were within specification.

Examination of the fracture surface on the No 1 blade socket showed that it had fractured due to the initiation and growth of high-cycle fatigue cracks, on opposite sides of the blade socket (Figure 5). The centres of the primary crack initiation zones were displaced about 20 degrees clockwise (looking down on the blade socket) from the fore/aft axis of the hub. The cracks originated in the first or second threads from the bottom of the threaded portion of the socket, corresponding to the most highly loaded threads. A notable feature was that the initial direction of propagation, near the crack origins, was in an axial direction upwards, with the cracks undercutting the tooth of the thread. This appeared to be the result of bending loads applied to the blade socket threads by the blade retaining nut (see Figure 7 showing a similar crack in No 2 blade socket). The fatigue cracks then turned outwards in a predominantly radial direction, before propagating circumferentially around the blade socket until failure, with relatively small regions of overload.

When the threads in the No 2 and No 3 blade sockets were inspected using the 2 MHz eddy current procedure specified in Service Bulletin 61-10-03 SB E 15, a large defect indication was found in the No 2 blade socket. Visual inspection using an optical microscope at low power confirmed the presence of an approximately 8 mm long crack at the base of the thrust flank of the first full thread in the bottom of the socket. This was in a similar circumferential location to one of the secondary fatigue crack origins in the No 1 blade socket (Figure 6). A section taken through the crack revealed that the direction of propagation was axial, undercutting the tooth of the thread (Figure 7). The depth of the crack into the material was approximately 2 mm.   When the crack was opened up to allow the surface to be viewed, evidence of fatigue propagation was seen.

Fretting damage was evident on the flanks of the threads in all three blade sockets, with the most severe fretting seen in the area closest to the primary crack initiation positions on the No 1 blade socket. This was indicative of relative movement having occurred between the blade retaining nut and the socket.

Measurements of the fatigue striation spacing on the fracture surface of the No 1 blade socket with the aid of a scanning electron microscope gave an estimate of 225,000 cycles from crack initiation to failure of the blade socket. This figure is considered to be conservative and does not in any case include the number of stress cycles required to initiate the cracking. It was not possible to estimate the length of time taken to form crack initiation to failure without a better understanding of the mode and frequency of the blade vibration, but this could not be determined from the available evidence.

History of propeller Hub serial No G22

At the time of the accident, the propeller hub had completed approximately 1,710 operating hours since manufacture in May 1999 and approximately 249 hours since previous overhaul in August 2003. The most recent workshop visit was in October 2003 when it was removed from G-BYUJ for repairs to superficial damage to the No 3 blade. After repair it was installed onto G-BYXJ on 8 January 2004.

At the previous overhaul in August 2003, the hub was inspected for cracks by a JAR-145-approved UK overhaul agency approved to carry out such inspections. The inspection included the threads in the blade sockets of the hub. Records show that the hub was reported to be free of cracks.

The most recent in-service inspection of the propeller was during a scheduled '50-hour' airframe inspection performed on 13 June 2004, at 1,259:55 airframe hours. Maintenance Instruction 49/04, which required removal of the propeller spinner to allow the blade ferrules to be inspected for cracks, was accomplished at the same time.

The next scheduled inspection of the propeller was due at 1,284:55 airframe hours (erroneously shown as 1,284:35 on the Technical Log page) for a repeat inspection of the blade ferrules per MI 49/04, coincident with an engine oil filter change. Due to oversights by the pilot and the maintenance organisation, the aircraft was offered and accepted for flight with 1,284:50 airframe hours and the inspection overran.

The removal history for hub serial number G22 shows that the No 1 and No 2 blade retaining nuts were found to have low torque values on two of the workshop visits and that the blade sets had been replaced a total of five times during the life of the propeller.

Examination of propeller Hub serial No G23

Hub G23, that had failed the initial eddy current crack check on the fleet, was sent to the AAIB for initial examination before being returned to the propeller manufacturer for further investigation. Examination, under a low power microscope, revealed a crack indication in the bottom thread in the region of the eddy current defect indication in the No 1 socket. The crack indication was located towards the rear of the blade socket and near the base of the thrust-bearing flank of the bottom thread (Figures 8 & 9). The external appearance and general location of the crack indication were similar to that of the crack found in the No 2 socket of hub G22.

Hub G23 had completed a total of 1,539 flying hours since new and 151 hours since previous overhaul.

Blade retaining nut torque values

The Service Bulletin inspection findings showed that a significant reduction in the blade retaining nut torque occurs in the first few hours of propeller operation, that may be associated with a bedding in process. The magnitude of this reduction is typically around 20 Nm. Breakaway torque values as low as 8 Nm were recorded at the initial 5 hour inspection and blade nut torque values of around 10-12 Nm were not uncommon. A test conducted by the AAIB on a newly assembled propeller showed that the blade retaining nut torque could be reduced to 10 Nm before blade shake could be detected.

Based on the inspection findings, the manufacturer increased the torque values for the blade retaining nuts from 30-40 Nm to 70 Nm. Subsequent checks showed that this provided a significant improvement in the residual preload on the nut, even given the average decrease of torque of around 20 Nm which occurs in first few hours of propeller operation.

The maintenance organisation subsequently introduced a requirement on newly installed propellers for a check of the blade retaining nut torques to be performed after the propeller balancing engine runs. It was established that re-torqueing the nuts to 70 Nm after the initial engine runs helped to maintain the blade retaining nut torque settings at acceptable levels over a longer period in service.

Control of maintenance and acceptance for flight

The function of maintenance planning is performed by the JAR-145 approved maintenance organisation with the aid of a computer-based maintenance planning tool. To assist in the day-to-day work planning, the next maintenance checks due are recorded against each aircraft tail number on a wall-mounted maintenance planning board. The number of flying hours remaining until the next scheduled maintenance (eg '50-Hour', '100-Hour' check, etc) are displayed for each aircraft and regularly updated. This is referred to on a daily basis by the company's base maintenance and line support engineers, who plan the day's operation accordingly. If an inspection should fall due during the day's operation, it is the responsibility of the line support engineer to withdraw the aircraft from service so that the inspection can be completed in time.

It was noted that the 25 hour requirement to replace the engine oil filter (at which time the propeller ferrule inspection in accordance with MI 49/04 was also due) which was also tracked on the maintenance board, did not display the flying hours remaining until the task was due, but rather the total airframe flying hours at which the task fell due. This made it more difficult to tell, at a glance, whether the task was likely to fall due during the day's flying operation.

The Aircraft Technical Log is also clearly annotated to show when the next maintenance is due, and it is the aircraft commander's responsibility under the requirements of the UK Air Navigation Order (ANO) to ensure that any necessary maintenance has been completed when signing the acceptance for flight. Notwithstanding this, enquiries revealed that the pilots did not always check the hours remaining until next inspection, thinking that this was the responsibility of the engineers. The operator has since amended their operational procedures to ensure that their aircrew comply with the ANO requirements for acceptance for flight.

Analysis

No evidence of was found of the aircraft having suffered a bird strike or in-flight impact with any other object therefore this possibility was discounted as a causal factor.

Given that the material properties of the hub G22 were acceptable and that the No 1 blade components did not exhibit excessive wear, there is no evidence to suggest that the failure was caused by any deficiency in the propeller hub, the blade or any of its components.

The lead propeller on the fleet had achieved approximately 2,400 flying hours to date, hub G22 had completed 1,700 flying hours when it failed and hub G23, which appears to be cracked, had completed 1,539 flying hours. This is the first failure on a fleet of 99 G115E aircraft. Whilst there appears to be no basic deficiency in the propeller design, there is clearly a long-term reliability issue with this propeller/aircraft combination. According to the manufacturer's estimates, even high loading cases such as snap roll manoeuvres are not likely to induce critical stresses in the propeller hub.

The high cycle fatigue failure observed in hub G22, with primary crack origins located on opposite sides of the blade socket and with similar rates of crack propagation in each location (Figure 5), is indicative of the blade socket having been subjected to cyclic stresses. The direction of the applied forces on the blade to produce such stresses is predominantly in the fore and aft direction.

The fact that the crack in the No 2 blade socket of hub G22 exhibited similar characteristics to the cracks in the failed No 1 socket, in that it was located at the base of the thrust flank of the bottom thread and was propagating in fatigue, suggests that a similar failure mechanism may have been at play in the No 2 socket.

The presence of cyclic stresses on the blade socket, leading to fatigue propagation at similar rates on opposite sides of the socket, opens up the possibility that the failure mechanism may be related to vibration. It is noteworthy that high torsional vibration levels, detrimental to engine ancillary components, are known to be present at engine speeds above 2,500 RPM.

The possibility of the causal factor being a discrete event, such as a propeller ground strike was considered, and whilst this remains a possibility, it is difficult to see how this would have induced fatigue cracks on opposite sides of the blade socket and it is likely that other witness marks associated with such an event would also have been evident.   Furthermore, a single event could not explain the presence of the fatigue crack in the No 2 blade socket. The presence of a crack indication in hub G23 further suggests that the problem may be more widespread.

The initial direction of crack propagation in the No 1 socket was predominantly in the fore-aft direction. The close spacing of the fatigue striations and the small areas of final overload failure show that magnitudes of the cyclic stresses were relatively low and that the stresses on the blade socket due to the centrifugal loading are not particularly high. There was insufficient evidence to enable the mode and frequency of the blade vibration to be determined. It was therefore, not possible to estimate the elapsed time from crack initiation to hub failure. Further testing, involving flight trials with a strain-gauged propeller, would be required to establish the levels of vibration experienced by the propeller and the resultant stresses in the blades and hub.

The presence of severe fretting on the flanks of the threads in the No 1 blade socket and to a lesser degree on the threads in the other blade sockets, is evidence that the blade retaining nuts had moved within the hub. If the blade is not rigidly retained in the socket, due to insufficient preload on the blade retaining nut, relative movement may occur during propeller operation. The loss of preload on the blade retaining nut would change the loading/stress characteristics within the hub, to the point where fatigue cracks could be initiated. Low blade retaining nut torque may therefore be a significant contributory factor, reducing the rigidity of the blade in the hub and allowing the blade more freedom to move in response to normal in-service loads or any vibration that may be present.

The fact that the blade retaining nut preload drops off very quickly in the first few hours of propeller operation may be indicative of a bedding in process occurring, due to initial wearing in of surfaces in contact, or redistribution of grease within the hub, or a combination of both. The introduction of a requirement to check-tighten the blade retaining nuts after an initial period of running has proved to be beneficial. The breakaway torque of 16.7 Nm of the No 2 blade retaining nut and the results of the fleet inspection, which highlighted torque values less than 10 Nm in some cases, shows that low blade nut torque is not an uncommon condition. Given that the blade retaining nut torque can fall as low as 10 Nm before any blade shake becomes detectable, it must be questioned as to whether blade shake is a satisfactory method for ensuring adequate preload on the blade nuts. Regular checks of the nut torques would provide greater certainty of ensuring the correct preload in the long term.

The surveys conducted by both the propeller and engine manufacturers showed a dramatic rise in the level of torque vibration at engine speeds above 2,500 RPM, believed to be associated with a crankshaft torsional resonance condition. This or any other source of vibration, could exploit any lack of rigidity of the blades in the hub and induce them to vibrate. This in turn would cause dynamic amplification of the stresses on the blade retaining nut and the blade socket to the point where fatigue cracking could be initiated. The higher than normal failure rates of various engine components, compared with similar general aviation aircraft, are further evidence of the high vibration environment on the G115E.

It cannot be said for certain whether the cracks in hub G22 were present at the previous overhaul in August 2003. If they had been however, they may have been overlooked given the difficulty of detecting cracks in threads using dye-penetrant inspection methods. It is likely that the use of an eddy current or other suitably reliable technique would increase the probably of detecting a crack in the early stages of development. The effectiveness of the 2 MHz eddy current test, contained in Service Bulletin 61-10-03 SB E 15, has been demonstrated in that the relatively small crack in the No 2 blade socket of hub G22 was easily detected long before the crack had reached a critical length. The disadvantage however, is that this method of inspection requires removal of the propeller blades, an operation which is undesirable on a frequent basis, given the cost implications and the possibility of inadvertent damage or increased wear occurring on the threads.

It is not possible to say whether the cracks in the hub would have been externally visible or if they may have been found had the 25-hour visual inspection of the propeller ferrules been performed when it fell due prior to the accident flight. Given these uncertainties, the fact that the inspection was not completed is not considered to be a contributory factor to the accident. It was apparent that there was a lack of appreciation amongst some pilots of their responsibility for ensuring that the necessary maintenance has been completed on the aircraft prior to accepting it for flight. The fact that the inspection was also overlooked by the engineers was a human factor error, in that by recording on the maintenance planning board the total airframe hours at which the inspection fell due rather than hours remaining, it was not obvious at a glance that the inspection would fall due during that day's flying operation. Both issues have now been resolved to the satisfaction of the operator and the maintenance organisation through procedural changes.

Conclusions

The cause of the propeller failure was a fracture of the No 1 blade socket due to extensive fatigue crack propagation culminating in an overload failure that allowed the No 1 blade to detach from the hub. The presence of fatigue origins on opposite sides of the blade socket, with similar crack propagation rates on either side, suggests that the propeller blade had been subjected to cyclic stresses possibly related to vibration. The presence of a small fatigue crack in the No 2 blade socket, in a similar location to one of the crack origins of the No 1 socket, suggests that the No 2 blade may have been similarly affected.

There is a tendency for the blade retaining nut torque to decrease rapidly in the first few hours of operation of a newly installed propeller. This leads to a reduction in the preload on the nut, reduces the rigidity of the blade retention in the hub and has the potential to increase the stresses in the hub.

Studies and in-service experience show that the Grob G115E experiences high levels of vibration that appear to be related to the torsional vibration behaviour of the engine crankshaft. Further testing is necessary to confirm the source of the vibration and its effect on the propeller and other parts of the aircraft.

Safety Recommendations

It was not possible, without further testing, to determine the precise nature of the vibration that caused the fatigue cracking in the No 1 and No 2 blade sockets. Given that no in-flight vibration testing has yet been performed on the Grob G115E airframe/engine/propeller combination, the following safety recommendation was made by the AAIB:

Safety Recommendation 2004-102 (made on 1 December 2004)

The aircraft manufacturer, GROB-WERKE Aerospace Division, should perform testing of the HO-V343K-V/183GY propeller on the engine/airframe combination of the Grob G115E, in order to establish the vibration characteristics of the propeller and the resultant stresses in the propeller blades and hub. This testing should also examine the effects of a loss in preload of the blade retaining nut.

In order to ensure the continued airworthiness of the type HO-V343K-V/183GY propeller on the Grob G115E aircraft, the following safety recommendations are made:

Safety Recommendation 2005-02

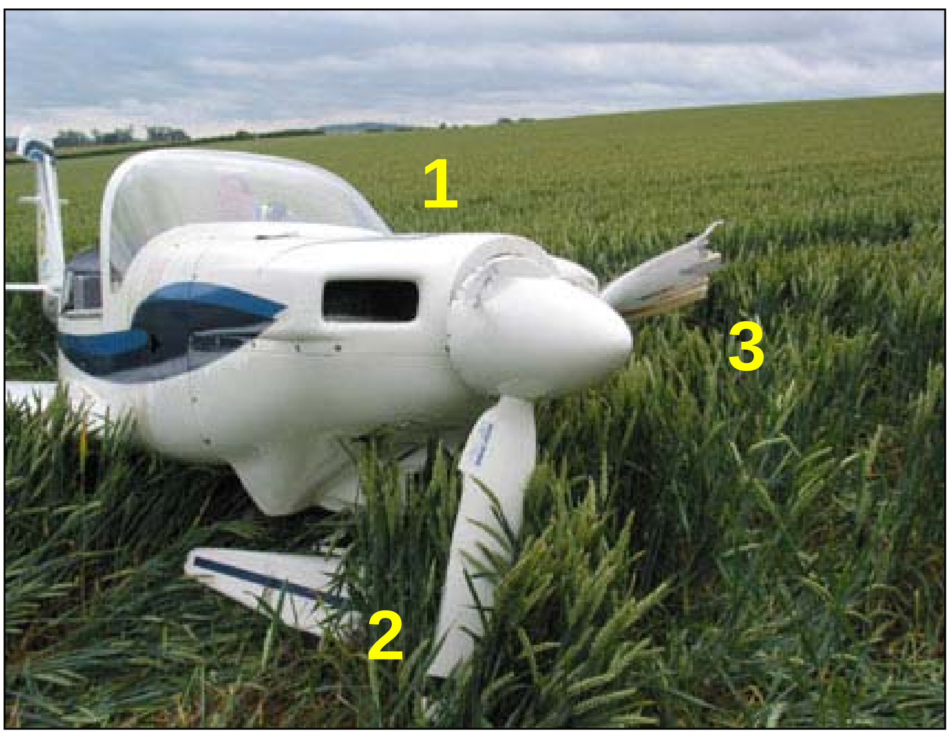
It is recommended that Hoffmann Propeller GmbH & Co KG introduce suitable maintenance procedures, or a suitable technical solution, for the type HO-V343K-V/183GY propeller on the Grob G115E, to ensure that the preload of the propeller blade retaining nut is maintained at an acceptable level.

Safety Recommendation 2005-03

It is recommended that Hoffmann Propeller GmbH & Co KG introduce adequate, high confidence level, non-destructive test (NDT) procedures, that will detect cracks in the threads of the type HO-V343K-V/183GY propeller blade sockets during overhaul and whilst in operational service on Grob G 115E aircraft.

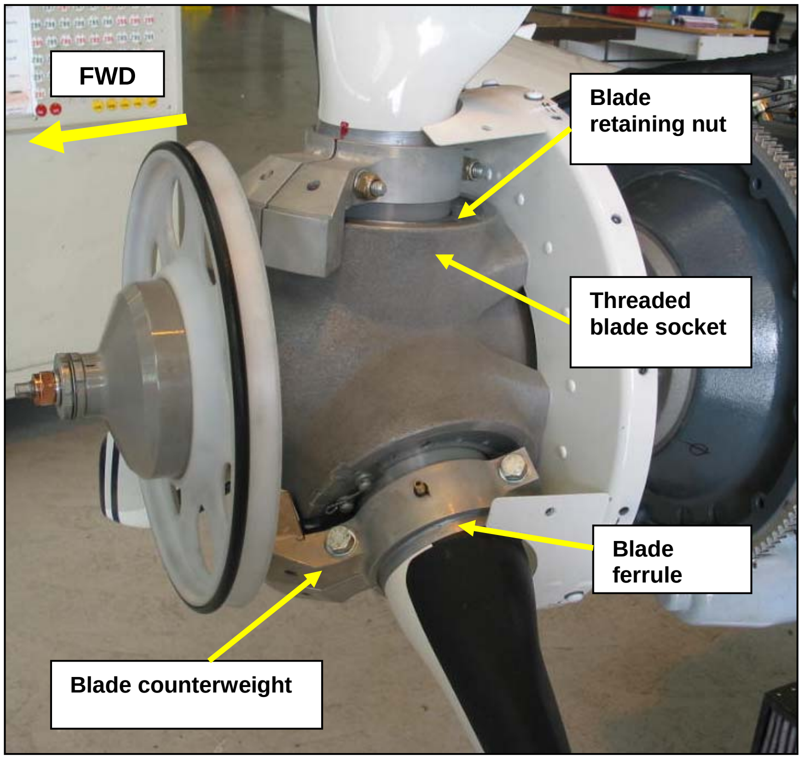
Propeller hub showing fractured No 1 blade socket

Figure 1



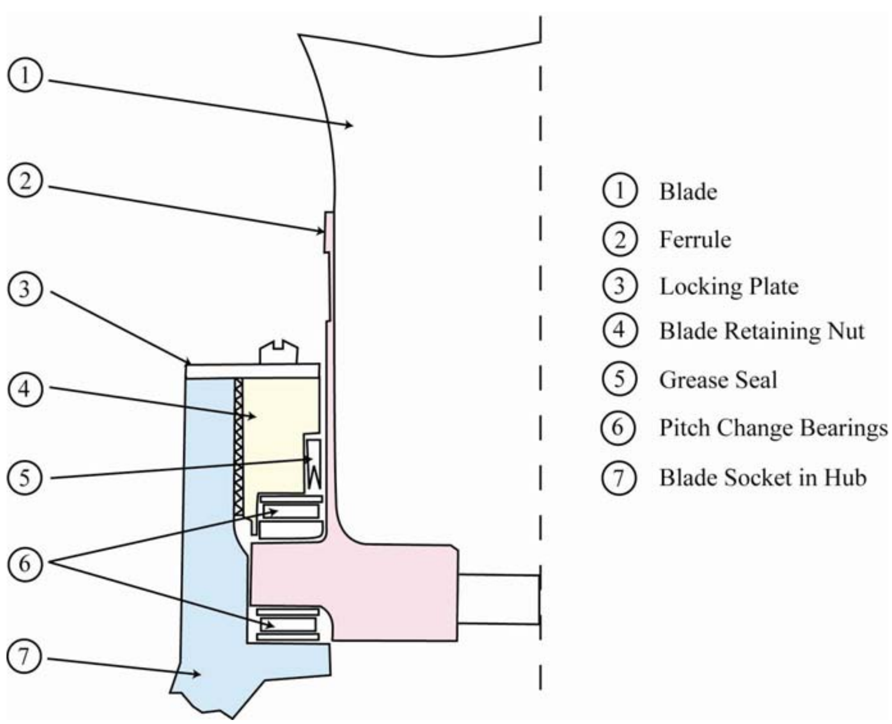
General view of propeller damage (blade locations numbered)

Figure 2



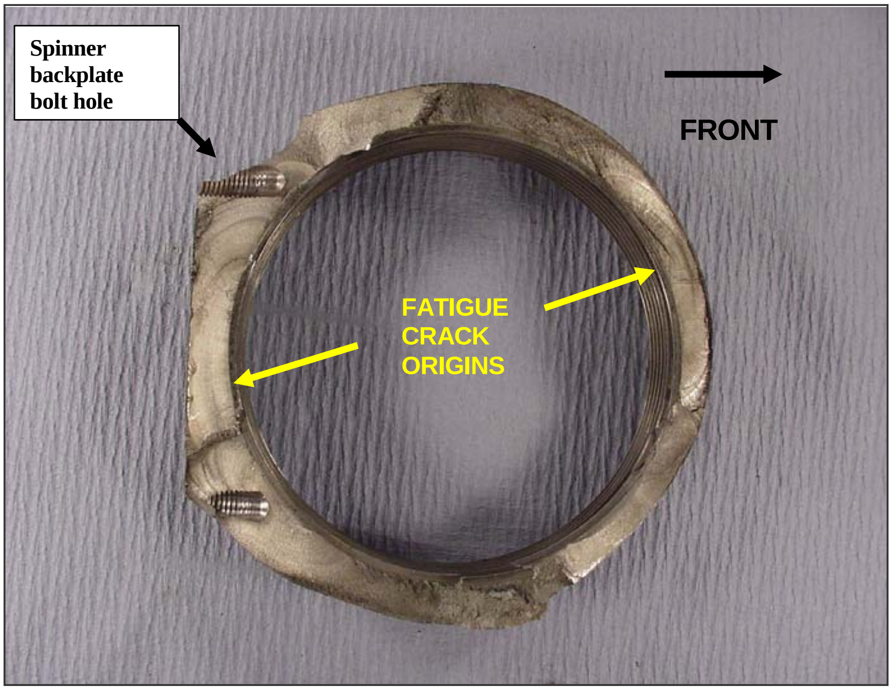
Grob G115E propeller assembly

Figure 3



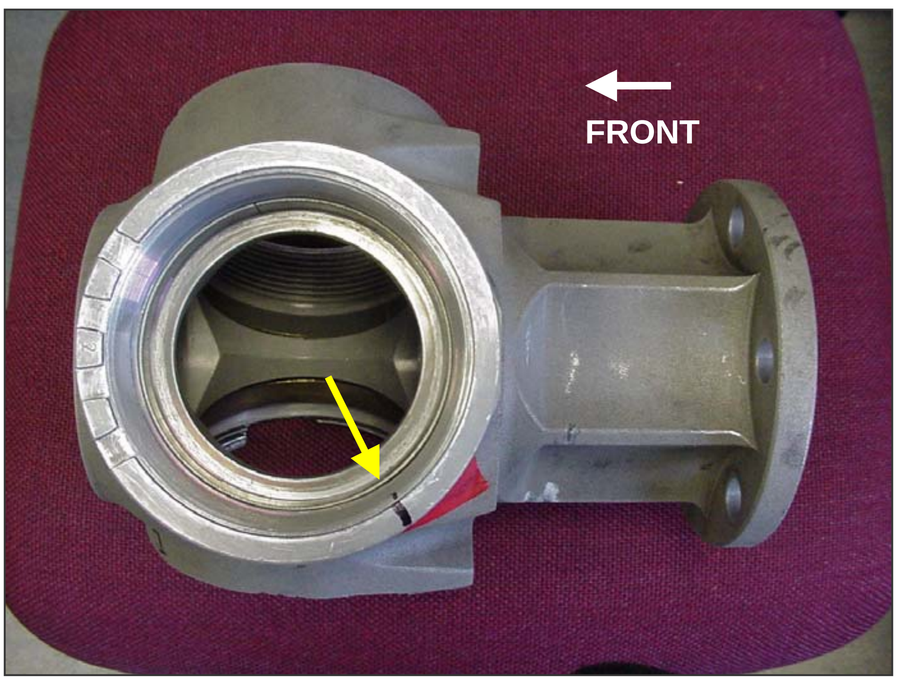
Part section through blade socket components

Figure 4



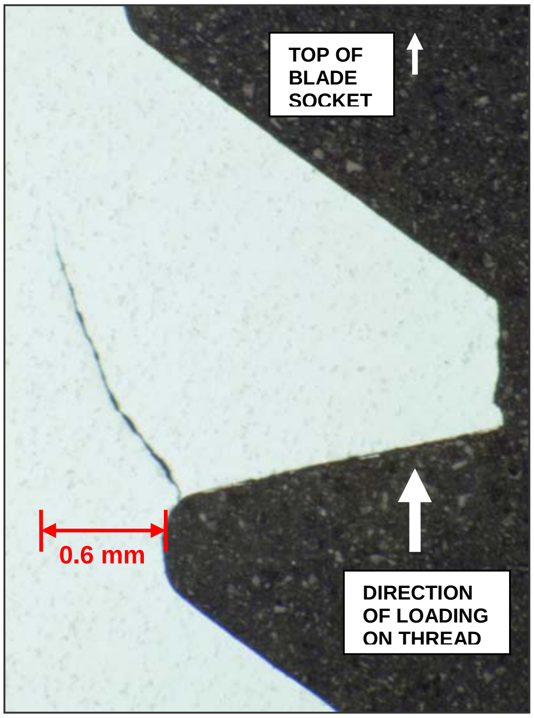
View on underside of separated portion of No 1 blade socket of Hub G22 showing locations of fatigue crack origins

Figure 5



Circumferential location of crack in bottom thread of Hub G22 No 2 blade socket

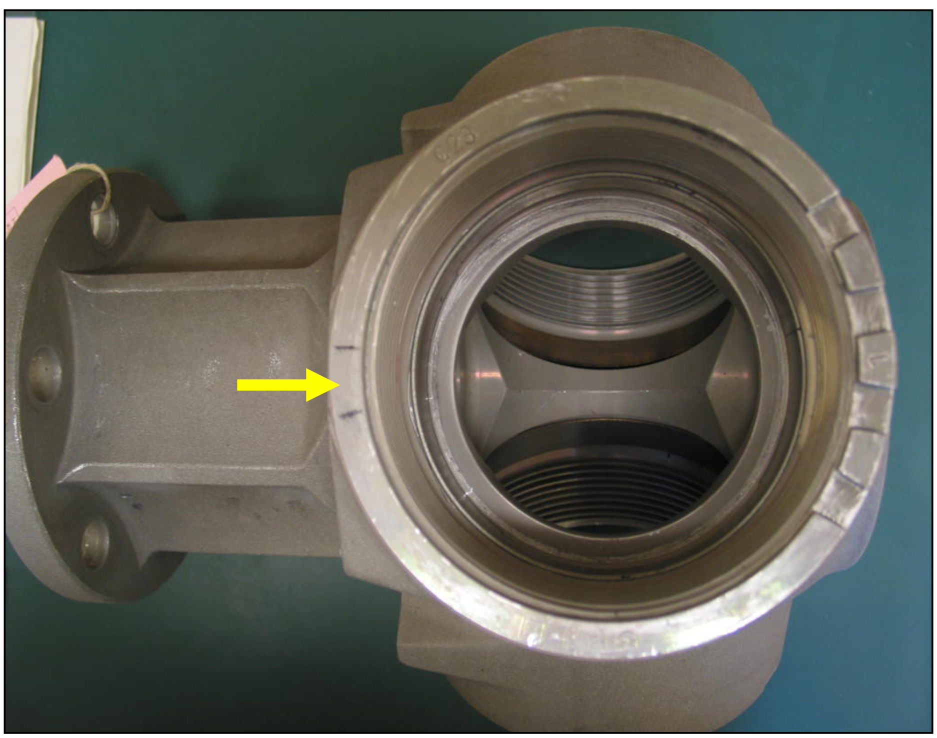
Figure 6



Fatigue crack in bottom thread of Hub G22 No 2 blade socket

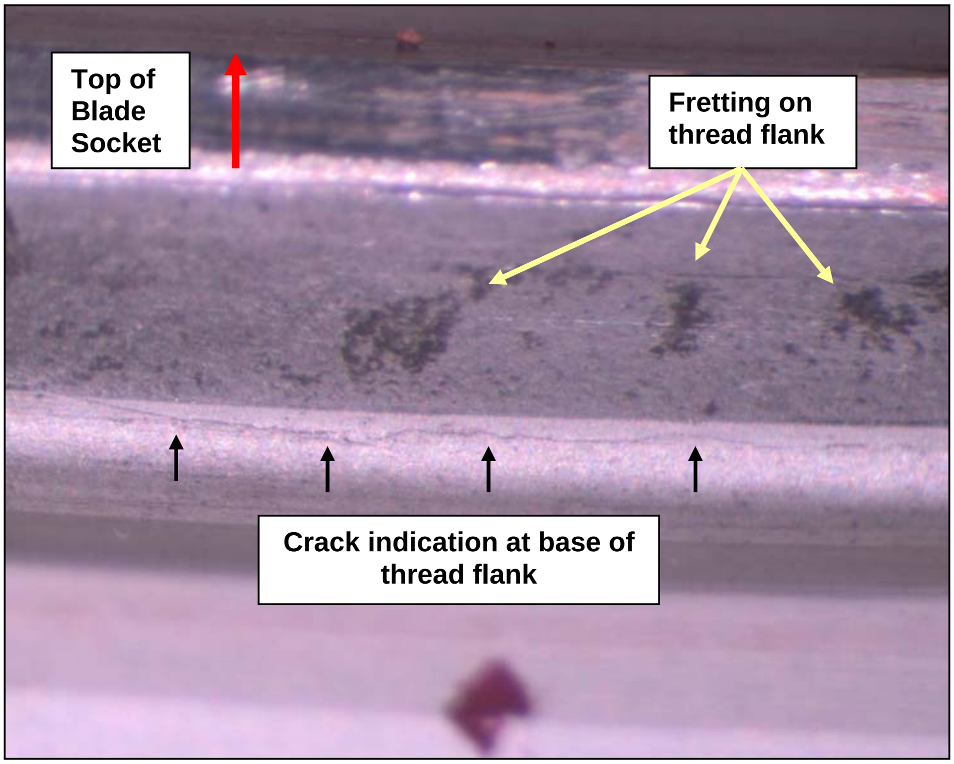
(Crack penetration depth approximately 2mm; crack detected using 2 MHz eddy current procedure)

Figure 7



Circumferential location of crack indication in bottom thread of No1 blade socket - Hub G23

Figure 8



Visual appearance of crack indication - Hub G23

Figure 9