**INCIDENT**

| | |
|---|---|
| **Aircraft Type and Registration:** | Miles M-65 Gemini 1A, G-AKKH |
| **No & Type of Engines:** | 2 Blackburn Cirrus Minor II piston engines |
| **Year of Manufacture:** | 1947 |
| **Date & Time (UTC):** | 24 August 2002 at 1300 hrs |
| **Location:** | Old Warden Aerodrome, Bedfordshire |
| **Type of Flight:** | Private |
| **Persons on Board:** | Crew - 1 Passengers - 1 |
| **Injuries:** | Crew - None Passengers - None |
| **Nature of Damage:** | Left Propeller separated from aircraft in flight |
| **Commander's Licence:** | Basic Commercial Pilot's License |
| **Commander's Age:** | 59 years |
| **Commander's Flying Experience:** | 4,950 hours (of which 30 were on type) |
| **Information Source:** | Field Investigation |

**History of flight**

The aircraft had been on a local flight when, whilst descending at a low throttle setting in the overhead of the airfield, the pilot heard a 'thump'. He then observed the left propeller, which had become detached from the engine, flying away after striking the nose of the aircraft. The aircraft returned to the airfield and landed without further incident. The propeller was recovered from a nearby field together with the hub sleeve; none of the propeller retaining bolts was found in the field but two of the bolt heads remained with the aircraft and were recovered from the cowling.

The owner of the aircraft had acquired it relatively recently and had flown it more frequently than had been the case in the recent past. The aircraft was being maintained to the Light Aircraft Maintenance Schedule (LAMS) and no special conditions or out-of phase maintenance items had been imposed. The last scheduled maintenance performed had been an Annual check, in February 2002, at which time the tightness of the attachment bolts of both propellers had been checked as required. Between that time and the incident, the aircraft had accumulated a further 24 hours flying time.

**Attachment of the propeller to the propeller hub** (Figure 1)

The propeller hub is fitted to the engine crankshaft on a keyed taper and secured by a nut and lock-washer. The eight propeller retaining bolts pass forward through the hub flange; these are retained loosely in place by the timing plate, which is a light, formed disc secured onto the rear of the hub. The hub sleeve, which centres the propeller, mounts on the hub with a friction disc interposed between the hub and sleeve flanges to transmit the engine torque to the sleeve. The propeller is clamped between the sleeve flange and the propeller boss flange plate; a thick plate which seats over the sleeve but is not keyed to it. The propeller retaining nuts have plain extensions which locate into the holes in the boss flange plate through which the retaining bolts pass. These nuts also retain the spinner back plate against the forward face of the boss flange plate. The retaining nuts are tightened to the required torque and are then turned on until the first available flat lies tangential to a circle about the hub centre and a nut locking plate is attached to the forward face of the spinner back plate. The torque to which the propeller retaining nuts should be tightened is not specified but has been established by practice at 18 lb.ft.

A review of the information available for the fitting of wooden propellers onto Cirrus Minor engines showed that there was some ambiguity over the correct assembly of the propeller onto the hub. The cross-section drawing of the propeller and hub assembly in the Cirrus Minor, Series II manual showed Belleville (dished) washers fitted between the propeller retaining nuts and boss flange plate. However, another illustration, showing the components needed for the assembly, and also the illustrated parts list showed no requirement for Belleville washers to be fitted; the propeller of the right engine was found to have been assembled onto its hub without Belleville washers.

**Examination of detached hub components and propeller**

The propeller hub, with the friction disc still adhering to its front face, had remained on the crankshaft. The friction disc material around the bolt-holes showed some very localised tearing distress and the rear face of the hub flange had hammered and polished areas around the bolt holes which were clearly the shape of the propeller retaining bolt heads. Whilst most of the bolt holes showed even polishing all round, two adjacent ones had polishing restricted to the counter-clockwise side when looking forwards (ie the advancing side). The bores of the bolt-holes were also polished and there was some bruising of the lips on the clockwise (retreating) side when looking forward.

The back face of the wooden propeller boss showed slight signs of heat build up and most of the bolt holes showed evidence of some hammering and polishing of the bores, close to the back face, on both the advancing and retreating sides. Two adjacent holes had been severely stretched in the driven (counter-clockwise looking forward) direction, this stretching reaching forward into both holes to about half the depth of the boss (Figure 2). All the other bolt holes in the propeller boss showed varying degrees of surface polishing and stretch.

The two propeller retaining bolt heads, which had remained with the aircraft, were submitted for metallurgical examination. This showed that both had been manufactured by machining from hexagonal steel bar and both had suffered fatigue due to reverse bending. On one, the fatigue progression had been relatively slow, predominantly from one side and the fatigue origins were almost diametrically opposite each other. On the second, the fatigue had been much more rapid and had also been predominantly from one side. On this second bolt, however, the origins were not diametrically opposite. In both cases the fatigue had originated in the machined radius between the bolt shank and the head.

The fractures observed on the two bolt heads recovered were typical of those which would be expected to result from running with insufficiently tightened propeller attachment bolts.

**Maintenance of correct attachment of wooden propellers to their hubs**

The organic characteristics of wood require particular and unusual considerations when establishing maintenance practices for the security of attachment of wooden propellers. The two principal considerations are the relatively low crushing strength of wood and the swelling and shrinkage of wood which occurs with increase and decrease of its moisture content. This latter consideration appears to be less relevant to the more modern wooden propellers which are, generally, thinner between the boss faces and have a more impervious surface finish. In general, in many of the older designs, the drive was transmitted from the crankshaft hub to the propeller boss by friction between the hub (or hub sleeve, in this case) and boss faces.

Because of the low crushing strength of wood, the propeller attachment bolts cannot be as heavily pre-loaded (torque tightened) as those for a metal propeller and are, consequently, liable to be in or close to a condition where engine/propeller loads can cause cyclic load variation in the bolts. The lower the pre-load in the attachment bolts, the greater is the possibility that there will be cyclic load variation in them and the more likely it will be that the bolts will suffer fatigue damage. An additional consequence of the low clamping forces exerted when bolt pre-load is low is an increased likelihood that the propeller will 'fidget' on the hub. This, in addition to causing bruising and fretting damage to the propeller boss clamping faces and bolt holes, may, in extreme cases, cause the boss faces to become charred. The wear caused by fidgeting will tend to decrease the insufficient clamping forces and thereby worsen the situation. If the attachment bolts become sufficiently loose they may tend to tip and consequently introduce cyclic bending into the bolt shank just below the head.

The retention of pre-load in a bolt depends both on the nut remaining stationary relative to the bolt thread and on the thickness of the assembly which is clamped between the nut and the bolt head remaining constant. The natural (unclamped) thickness of the boss of a wooden propeller varies with its moisture content which is influenced by changes in atmospheric conditions. Thus, once the retaining nuts have been set, the pre-load in the attachment bolts will increase if the wood swells and there will be an attendant risk of crushing the wood. This is likely to occur if the nuts have been tightened up when the propeller wood was very dry. Crushing resulting from pre-load may not be evenly distributed round the hub and can lead to an 'unsquare' condition which would result in some combination of bad tracking of the propeller blade tips and unequal blade pitch. Both of these conditions are conducive to propeller induced vibration. Conversely, if the propeller hub is fitted when the wood is moist and it dries out after the bolts have been tightened, the pre-load will reduce and the propeller retaining bolts will be subjected to cyclic loading and may suffer fatigue damage.

In some designs, in order to try to retain a more stable clamping force when propeller boss shrinkage or swelling occurs with climatic change, Belleville washers are used. These act as extremely high rate springs between the retaining nuts and the boss flange plate and allow the clamped thickness to vary over a very small range whilst minimising the resulting variation of clamping force. Belleville washers are usually, but not universally, used in the hub assemblies of older designs of wooden propeller. They have, theoretically, a more marked effect on the clamping stability of thicker propeller hubs where the difference in the moduli of elasticity of wood and steel and the potential for thickness variation with moisture content have the greatest significance.

Where Belleville washers, or similar, are not, by design, components of the hub (as is the case for the Gemini/Cirrus Minor installation), the clamping force exerted by the bolts will be dependent on the predominant short term (a few days) atmospheric conditions.

**Maintenance of G-AKKH**

This aircraft was being maintained to the CAA Light Aircraft Maintenance Schedule (LAMS) and no special conditions or out-of phase maintenance items, in particular any related to the propeller attachment, had been imposed. The organisation which had performed the most recent maintenance work on the aircraft had become responsible for it in February 2002, at which time the aircraft had accumulated a total flying time of 1,438 hrs. They performed an Annual Check on the aircraft at that time, during which a check of the security of the propeller attachment bolts was required and was recorded as having been completed on both propellers.

According to the requirements of the basic LAMS, the propeller tightness should be checked every 50 flying hours or 6 months. Following the maintenance in February, no further work was scheduled before the time at which the left propeller became detached in flight; at which time the aircraft had flown 24 hours since the Annual and was almost due for a 6 month check. Some unscheduled maintenance had been performed but none relating to the security of the left propeller. It was concluded that the security of both propeller attachments had been correctly maintained with reference to the approved schedule in force.

The propeller security was checked at a time when the wood would have been expected to have been in its most moist and swelled condition and the securing bolts at their coldest and therefore at their shortest length. The maintenance organisation's records show, however, that the aircraft had been in their heated hangar for some 10 days before this work was done and, as a result, the tightness of the nuts would have been checked in relatively warm and dry conditions. Following this maintenance, the aircraft would subsequently have been operated in winter conditions and this environmental change would have tended to alter the assembly into an effectively overtightened condition as the bolts shortened and the wood swelled. Since this propeller assembly does not have the clamping force stabilising effect of Bellville washers to compensate for these changes, this could have lead to some very slight crushing of the propeller which could have been exploited when the weather turned warmer.

**Historical requirements for maintenance of the propeller attachment**

During the investigation several mutually contradictory, legitimate, schedules for the maintenance of the security of the propeller attachment were found. The manufacturer's original Miles M-65 1A "Gemini" Aircraft Service Manual, dating from October 1946, required the tightness of the propeller attachment bolts to be checked every 10 flying hours. There was also the additional requirement, for newly fitted propellers, that the tightness of the bolts should be checked after two or three flights; this check being specified in both the 'Daily inspections' and in the '10 hour inspections'. No torque to which the nuts should have been tightened was given; this was not abnormal at the time that this Manual was compiled.

The engine manual, also dated 1946, contained a detailed description of the propeller attachment, but similarly did not specify a torque to which the nuts should have been tightened. This manual did not give any periodicity for checking the tightness of the nuts. Confusingly, this manual contained a cross-section illustration of the propeller hub assembly which suggested that Belleville washers should have been fitted between the retaining nuts and the hub front plate. However, these washers were not shown in the Illustrated Parts List, they were not shown in a photograph of the parts making up the assembly in the Manual and nor was any mention of them made in the manual text. The bolts of the right propeller hub of the incident aircraft were observed to be insufficiently long to accommodate the fitting of Bellvilles.

There was a Mandatory modification (AD), first issued in December 1946, applicable to the hub assembly of this engine type. This had been applied on the incident aircraft. The modification resulted in an increased area of the clamped surfaces on the front and back faces of the propeller boss. The requirement for this arose from the discovery of crushing and indentation damage to the clamped faces of a number of propellers which had resulted from tightening of the hub nuts.

In a later Engine Instruction Manual, issued by Bristol Siddeley in 1964, the Check 1 interval was set at 50 hours, which is the same as that for aircraft maintained to the LAMS Schedule. In this Manual, a Special Check was required if wooden propellers were fitted. This specified the intervals for checking the tightness of the propeller securing nuts. These were:- after the first flight following the fitting of a wooden propeller and after every subsequent 25 hours running.

**Discussion**

It would appear that, over time, the interval between checks of the security of the propeller, if the basic LAMS is followed, has been extended fivefold from its original period. In the case of this incident, the propeller separated from the aircraft less than 25 flying hours or 6 months after its last scheduled check, which was consistent with the most recent schedule published by the Type Certificate holder. Had the original schedule been in force, two intervening checks of the tightness would have been performed. It appears that, because the design of this assembly does not include the clamping stabilisation afforded by Bellville washers, it would be prudent to require the more frequent checking afforded by the original schedule.

In CAP 520, the CAA publication concerning Light Aircraft Maintenance, the need to consider 'customising' the LAMS for a specific aircraft type is stated with particular, though not exclusive, emphasis on mandatory requirements. Such items need to be recorded in CAP 543 which forms part of the schedule.

This investigation has shown that the general application of the basic LAMS schedule to historic aircraft may leave some of their less usual features inappropriately maintained. Although in this particular case the maintenance involved was restricted to the propeller attachment, there may be several areas in which the methods of construction and materials require more frequent maintenance than is usual with more modern constructions. As was seen in the original Gemini Service Manual, several items were scheduled for 10 hour, 20 hour and 40 hour maintenance intervals and it is most probably amongst these, and any items which may be seasonally affected, that requirements different from those of the basic LAMS may occur.

It is therefore recommended that:

**Safety Recommendation 2004-104**

The Civil Aviation Authority should, when approving the application of the Light Aircraft Maintenance Schedule to historic aircraft, review the appropriateness of the resulting inspection intervals against those of the original Maintenance Schedule, if this is available, and require out of phase maintenance actions where appropriate.

Figure 1a:-
Right propeller installation
(Spinner and lock plate removed)
Note NO Belleville washers

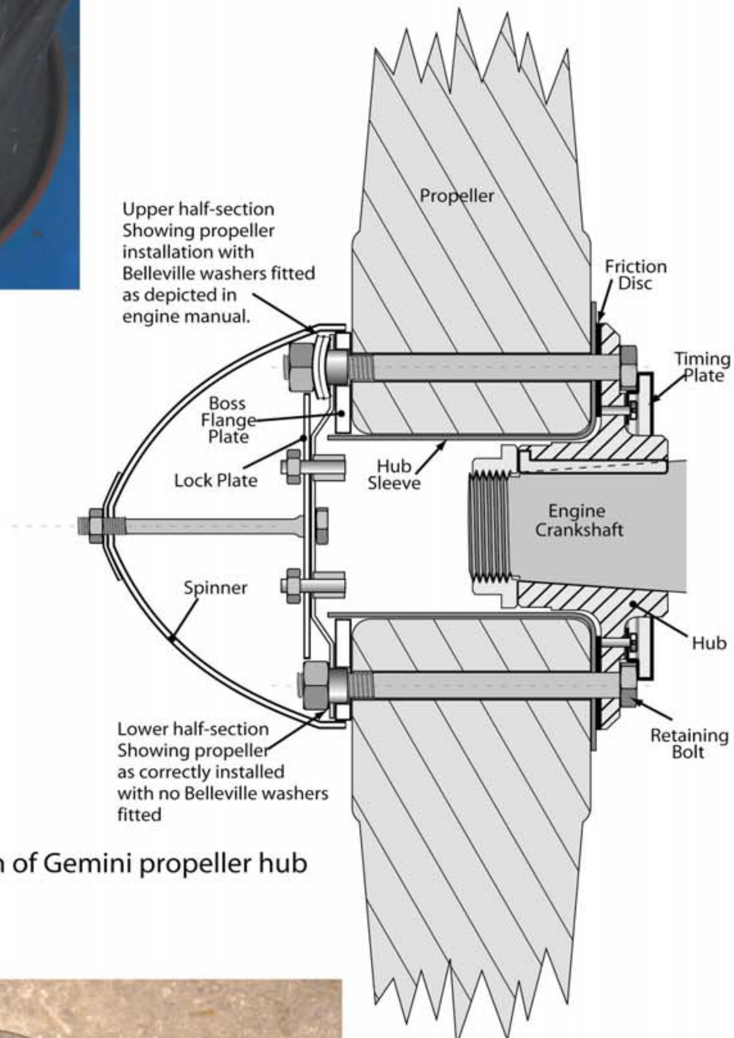


Figure 1:-
Cross section of Gemini propeller hub

Figure 2:- Aft face of left propeller (note elongated holes)